W T. Olson
TN
1714)

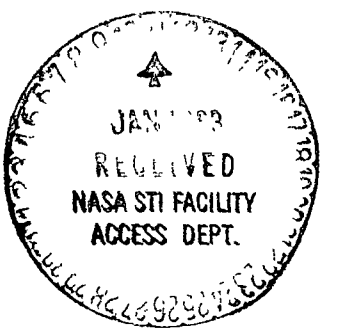
AEROPROPULSION 1979

Confe

NASA Lewis Research Center
Cleveland, Ohio

May 15-16, 1979

FIGURE
PREPRINTS



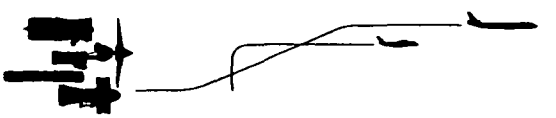


Figure Preprints

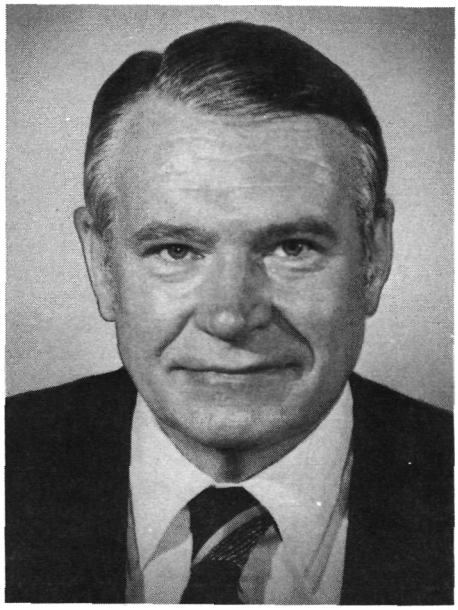
AEROPROPULSION 1979

Conference

Lewis Research Center
Cleveland, Ohio

May 15-16, 1979

NASA
National Aeronautics and
Space Administration



John F. McCarthy, Jr.
Director, Lewis Research Center

Dr. McCarthy came to Lewis in 1978 from the Massachusetts Institute of Technology, where he was the Director of MIT's Center for Space Research from 1974 to 1978 and Professor of Aeronautics and Astronautics from 1971 to 1978.

From 1971 to 1978, Dr. McCarthy chaired the Aeronautical Systems Division Advisory Group of the Air Force Systems Command. In 1973 he was awarded the Meritorious Civilian Service Award by the Air Force for his work on the C-5A transport airplane, and in 1978 he received the Decoration for Exceptional Civilian Service for his distinguished service as a member of the Air Force Scientific Advisory Board.

Dr. McCarthy went to MIT from the Los Angeles Division, North American Rockwell Corporation (now Rockwell International Corporation), where he was Vice President, Systems Engineering. Other key positions held earlier at North American Rockwell included Vice President, Research and Engineering; Executive Vice President, Los Angeles Division; Vice President, Research and Engineering, North American Aviation Divisions Office, Los Angeles; Vice President of Research Engineering and Testing for the Space Division, Downey, California; Assistant Chief Engineer, Apollo; and Apollo Directorships in Control Systems, Space Sciences, and Technology.

At the Space Division, he was involved with the basic design and testing of the Apollo command and service modules and the S-II stage of the Saturn V launch vehicle, which successfully performed the manned lunar landings.

Dr. McCarthy received S.B. and S.M. degrees in aeronautical engineering from MIT in 1950 and 1951 and a Ph.D. degree in aeronautics and physics from the California Institute of Technology in 1962. He completed the Executive Program at UCLA's Graduate School of Management in 1966.

He left military service in 1946 to become Supervisor of Air/Ground Communications for TWA in Rome, Italy. In 1951, after graduation from MIT, he joined the staff of MIT's Aeroelastic and Structures Research Laboratory. At MIT, he was responsible for the design and operation of one of the first variable Mach number supersonic test sections, in which he performed some of the earliest successful supersonic flutter tests. He also did extensive research in aerodynamics, loads, aeroelasticity, and vehicle dynamics.

In 1955, he left MIT to become Operations Analyst at Headquarters, Strategic Air Command, Offutt Air Force Base, Nebraska, serving as advisor to the Commander in Chief and staff on scientific analyses and analytical techniques. There, he was a key figure in system definition and selection, and his efforts were formally recognized by letters and awards from the senior command.

He is the author of numerous technical papers, a contributor to four textbooks, a Fellow and former director of the American Institute of Aeronautics and Astronautics (AIAA), an Associate Fellow of the Royal Aeronautical Society, and a member of Sigma Gamma Tau, the Research Society of America, and Sigma Xi.

He is a member of the Aerospace Vehicle and Strategic Panels of the Air Force Scientific Advisory Board, a member of the American Management Association's President's Council, and a former member of the Executive Committee of the Aerospace Division of the American Society for Engineering Education. He was a member of the NASA Research and Technology Advisory Council, Panel on Space Vehicles, from 1974 to 1977. From 1965 to 1967, he served as a member of the NASA Research Advisory Committee on Space Vehicle Aerodynamics. He was a consultant to the Office of the Director of Defense Research and Engineering (ODDR&E) in 1976, and he has been a member of the Joint Strategic Target Planning Staff (JSTPS), Scientific Advisory Group, for the Joint Chiefs of Staff since 1976.

Dr. McCarthy was born in Boston on August 28, 1925.

WELCOME

Welcome to NASA's Lewis Research Center and to this Aeropropulsion Conference.

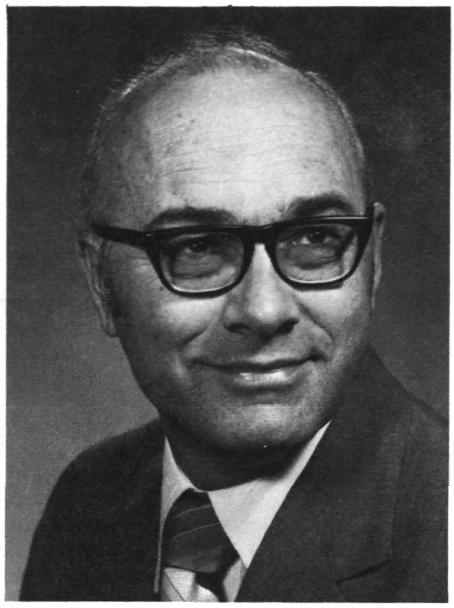
The Lewis Research Center has a 37-year heritage of providing advances in aeronautical propulsion from the research activities of its staff and its university and industrial grantees and contractors. These advances have helped create the preeminence in aeronautics that has contributed to our national defense, has provided swift, reliable transportation for our people and their goods, and has so greatly aided our position in international trade.

Although the results of the Center's projects and programs are reported as they are obtained, from time to time a conference such as this one affords the opportunity for a broad overview and an in-depth interpretation of a large body of results and for informal discussions about the subject.

We hope you will find the conference informative and useful and that you will inquire further about whatever may be important to you.

John F. McCarthy, Jr.

Page intentionally left blank



Warner L. Stewart
Director of Aeronautics, Lewis Research Center
Conference Chairman

In May 1948, Mr. Stewart joined the staff of the National Aeronautics and Space Administration's Lewis Research Center as the Center's first co-op. The co-op program at Lewis allows students to attend college part time and to get on-the-job training in their fields.

A native of Cincinnati, Ohio, he received a B.S. degree in aeronautical engineering from the University of Cincinnati in 1949 and an M.S. degree in aeronautical engineering from Case Institute of Technology (now Case Western Reserve University) in 1951.

Mr. Stewart was Chief of the Center's V/STOL and Noise Division before he was appointed Director of Aeronautics in 1974. In this position he oversees four research divisions and a major project office, with a staff of over 450 persons. The Aeronautics Directorate is developing technology that will allow future engines to be more fuel conservative and quieter and to have substantially lower emissions than current engines. It is also exploring new engine concepts for such advanced applications as supersonic-cruise and vertical-takeoff-and-landing aircraft.

A recognized authority on turbines for propulsion and power-generating systems, Mr. Stewart has written more than 50 papers on these subjects. He has served as Chairman of the Gas Turbine Division of the American Society of Mechanical Engineers and is a Fellow of that society. He also is a member of the American Institute of Aeronautics and Astronautics. In addition, he has received the NASA Exceptional Service Medal.

Page intentionally left blank

CONTENTS

I. AIRCRAFT ENERGY EFFICIENCY (ACEE) STATUS REPORT
Donald L. Nored, Chairman; James F. Dugan, Jr.;
Neal T. Saunders; and Joseph A. Ziemianski

II. EMISSION REDUCTION
Donald A. Petrash, Chairman; Larry A. Diehl;
Robert E. Jones; and Edward J. Mularz

III. NOISE REDUCTION
Charles E. Feiler, Chairman; John F. Groeneweg; Francis J. Montegani;
John P. Raney; Edward J. Rice; and James R. Stone

IV. ALTERNATIVE FUELS
Jack Grobman

V. MATERIALS AND STRUCTURES TECHNOLOGY
Robert A. Signorelli, Chairman; Thomas K. Glasgow;
Gary R. Halford; and Stanley R. Levine

VI. COMPUTATIONAL FLUID MECHANICS OF INTERNAL FLOW
David N. Bowditch, Chairman; John J. Adamczyk; Bernhard H. Anderson;
William D. McNally; and Peter M. Sockol

VII. TURBOMACHINERY TECHNOLOGY
Cavour H. Hauser, Chairman; Jeffrey E. Haas
Lonnie Reid; and Francis S. Stepka

VIII. MECHANICAL COMPONENTS
William J. Anderson, Chairman; Robert C. Bill;
John J. Coy; and David P. Fleming

IX. INSTRUMENTATION TECHNOLOGY
William C. Nieberding, Chairman; David R. Englund, Jr.;
and George E. Glawe

X. CONTROL TECHNOLOGY
John R. Szuch

XI. SUPERSONIC PROPULSION TECNOLOGY
Albert G. Powers, Chairman; Robert E. Coltrin; Leonard E. Stitt;
Richard J. Weber; and John B. Whitlow, Jr.

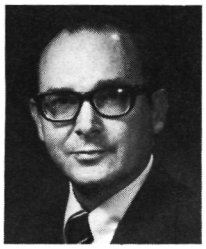
XII. HYPERSONIC PROPULSION
H. Lee Beach, Jr.

XIII. VERTICAL TAKEOFF AND LANDING (VTOL) PROPULSION TECHNOLOGY
Carl C. Ciepluch, Chairman; John M. Abbott; Royce D. Moore;
and James F. Sellers

XIV. HIGH PERFORMANCE VEHICLE TECHNOLOGY
Louis A. Povinelli

I. AIRCRAFT ENERGY EFFICIENCY (ACEE) STATUS REPORT

Donald L. Nored, Chairman
James F. Dugan, Jr.
Neal T. Saunders
Joseph A. Ziemianski

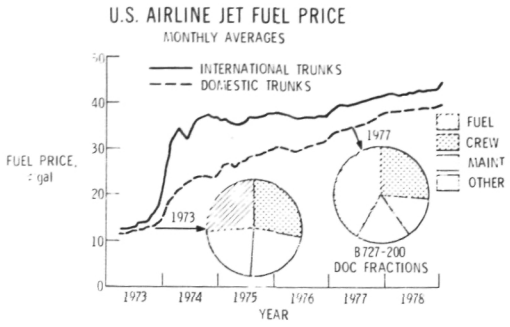


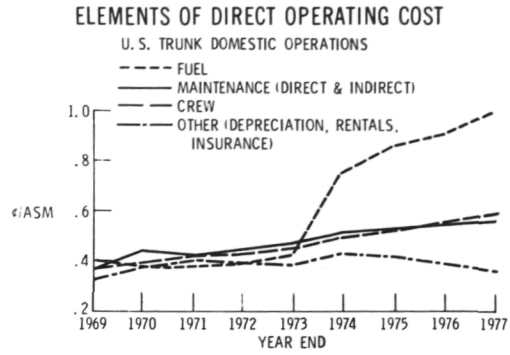
DONALD L. NORED is Chief of the Energy Conservative Engines Office at NASA Lewis, whose staff he joined in 1955. A native of Texas, he was awarded a B.S. degree in chemical engineering by Texas Technological University in 1955 and completed the Program for Management Development at the Harvard Business School in 1971. He has specialized in research and project management in liquid rocket systems, rocket propellants, cryogenics and insulation, high-power lasers, and energy and energy storage systems and most recently in management of fuel-efficient aircraft propulsion programs.

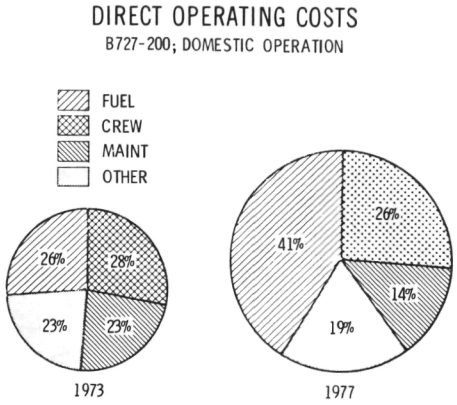
JAMES F. DUGAN, JR., received a B.S. degree in aeronautical engineering and an M.S. degree in engineering mechanics from the University of Notre Dame. Since joining the staff of the Lewis Research Center (then part of the National Advisory Committee for Aeronautics) in 1948, he has published over 40 reports on airbreathing propulsion systems and airplane-mission studies. He is an Associate Fellow of the AIAA and has served as a member of its Technical Committee on Airbreathing Propulsion. He currently manages all NASA activities in its Advanced Turboprop Project, part of the Energy Conservative Engine Office.

NEAL T. SAUNDERS is Manager of the Energy Efficient Engine Project, Energy Conservative Engines Office, at NASA Lewis. He began his Lewis career in 1958 after earning a B.S. degree in metallurgical engineering from Michigan State University and working for a year in the nuclear industry. He has pursued graduate studies in engineering at Carnegie-Mellon University and Case Western Reserve University and completed the Program for Management Development at the Harvard Business School in 1974. Before being appointed to his current position in 1977, he was Chief of the Materials Applications Branch, where he specialized in developing and applying advanced materials and manufacturing processes.

JOSEPH A. ZIEMIANSKI was named Manager of the Engine Component Improvement Project, Energy Conservative Engines Office, at NASA Lewis in 1976. In 1955, he received a B.S. degree in engineering from Youngstown State University, and from 1955 to 1963 was employed at Goodyear Aerospace Corp. Since coming to Lewis in 1963, he has held various responsibilities and, in 1975, he was awarded NASA's Exceptional Service Medal for his work in the NASA Unmanned Launch Vehicle Program.





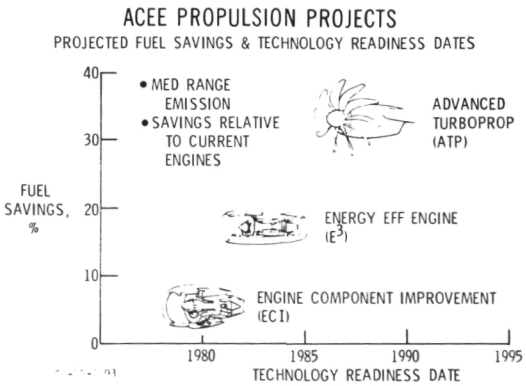


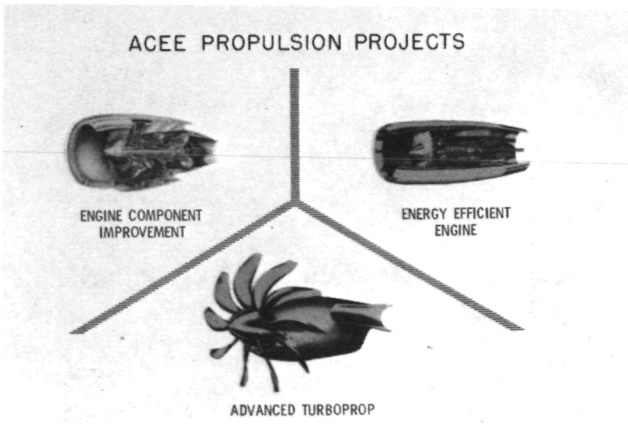
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
AIRCRAFT ENERGY EFFICIENCY PROGRAM

AERODYNAMICS
- ENERGY EFFICIENT TRANSPORT
- LAMINAR FLOW CONTROL

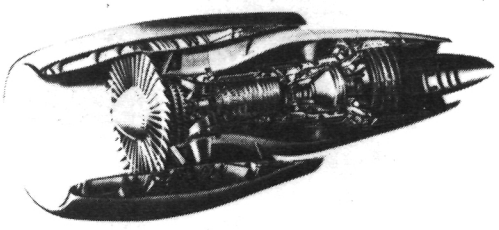
AIRCRAFT STRUCTURES
- COMPOSITE COMPONENTS & PRIMARY STRUCTURES

PROPULSION
- ENGINE COMPONENT IMPROVEMENT
- ENERGY EFFICIENT ENGINE
- ADVANCED TURBOPROP





ENGINE COMPONENT IMPROVEMENT PROJECT



PERFORMANCE IMPROVEMENT

ENGINE DIAGNOSTICS

GOAL OF 5% FUEL SAVINGS

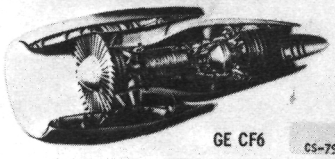
CS-79-2099

PERFORMANCE IMPROVEMENT

P & WA JT8D

P & WA JT9D

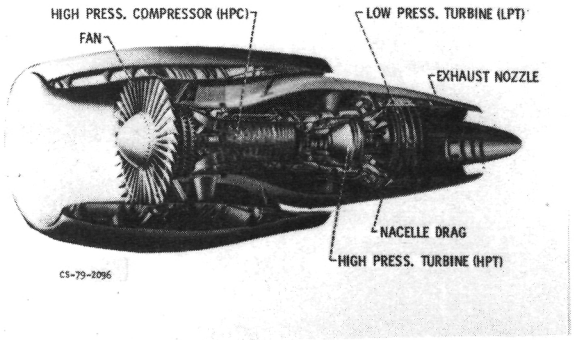
DEVELOP TECHNOLOGY FOR COMPONENTS TO REDUCE FUEL CONSUMPTION IN NEW PRODUCTION OR RETROFIT OF CURRENT ENGINES BY 1980-1982



GE CF6

CS-79-2098

COMPONENT AREAS



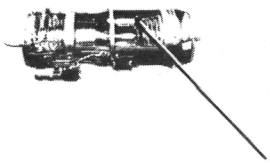
CS-79-2096

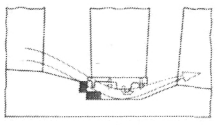
TECHNOLOGY AREAS

IMPROVED AERODYNAMICS
REDUCED CLEARANCES
MORE EFFECTIVE COOLING
IMPROVED MATERIALS

CS-79-2079

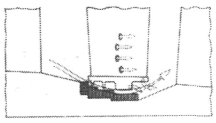
JT8D HPT OUTER AIR SEAL





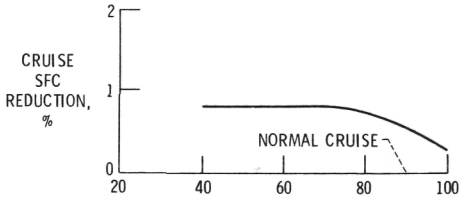
CURRENT

ADDED KNIFE-EDGE SEAL
ADDED HONEYCOMB SEAL
COOLING AIR DISCHARGE RELOCATED
CRUISE SFC REDUCTION, 0.6% DEMONSTRATED



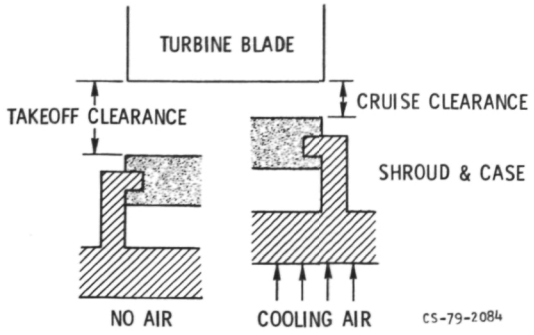
IMPROVED

JT8D HPT OUTER AIR SEAL ENGINE TEST

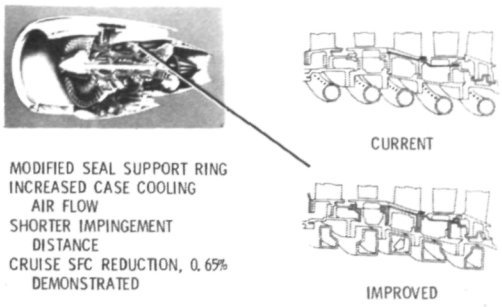


CS-79-2082

ACTIVE CLEARANCE CONTROL

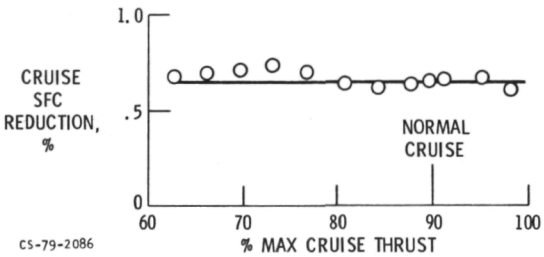


JT9D HPT ACTIVE CLEARANCE CONTROL

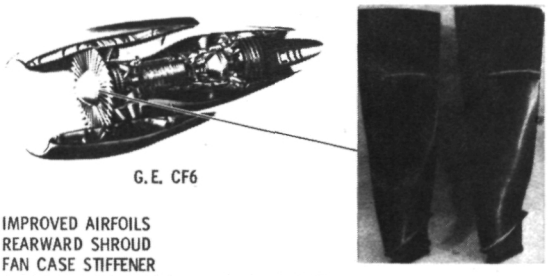


MODIFIED SEAL SUPPORT RING
INCREASED CASE COOLING AIR FLOW
SHORTER IMPINGEMENT DISTANCE
CRUISE SFC REDUCTION, 0.65% DEMONSTRATED

JT9D HPT ACTIVE CLEARANCE CONTROL TEST DATA



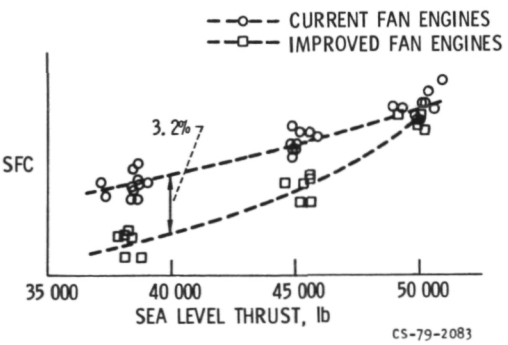
CF6 FAN



IMPROVED AIRFOILS
REARWARD SHROUD
FAN CASE STIFFENER
CRUISE SFC REDUCTION, 2% DEMONSTRATED

CS-79-2097

CF6 ENGINE TEST COMPARISON



PERFORMANCE IMPROVEMENT CONCEPTS

CONCEPTS	% SFC REDUCTION	COMPLETION DATE
P & WA JT8D ENGINE		
HPT OUTER AIR SEAL	0.6	SEP 1978
NEW HPT BLADE	.9	DEC 1979
REVERSER STANG FAIRING	.5	SEP 1980
TRENCHED ABRADABLE HPC	.9	DEC 1980
P & WA JT9D ENGINE		
HPT ACTIVE CLEARANCE CONTROL	.7	NOV 1978
NEW FAN TECHNOLOGY	1.3	FEB 1979
HPT ABRADABLE OUTER SEAL	.3	JUN 1980
HPT VANE THERMAL COATING	.1	FEB 1981

PERFORMANCE IMPROVEMENT CONCEPTS

CONCEPTS	% SFC REDUCTION	COMPLETION DATE
GE CF6 ENGINE		
SHORT CORE NOZZLE	0.9	FEB 1979
NEW FRONT MOUNT	.3	MAR 1979
IMPROVED FAN	2.0	MAY 1979
HPT AERO REFINEMENT	1.3	JUL 1979
HPT ROUNDNESS CONTROL	.4	MAY 1980
REDUCED HPC BLEED	.7	SEP 1980
LPT ACTIVE CLEARANCE CONTROL	.3	OCT 1980
HPT ACTIVE CLEARANCE CONTROL	.6	AUG 1981

PERFORMANCE IMPROVEMENT

INCORPORATION OF ALL CONCEPTS LISTED INCLUDING RETROFIT YIELDS A CUMULATIVE FUEL SAVINGS THROUGH THE YEAR 2000 OF:

7 BILLION gal

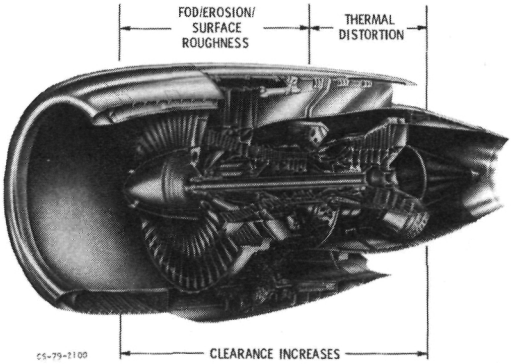
CS-79-2101

ENGINE COMPONENT IMPROVEMENT
ENGINE DIAGNOSTICS

PROVIDE INFORMATION & TECHNOLOGY WHICH CAN BE USED TO MINIMIZE THE PERFORMANCE DETERIORATION OF CURRENT (JT9D & CF6) & FUTURE ENGINES

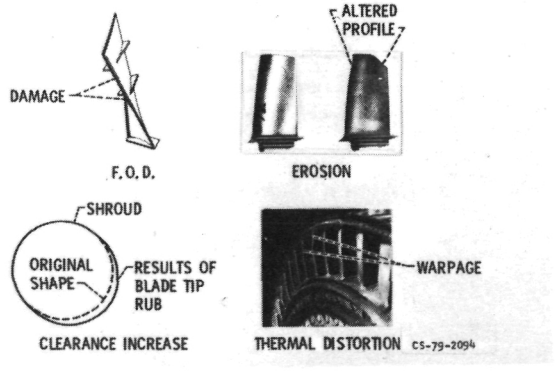
CS-79-2087

ENGINE PERFORMANCE DETERIORATION



CS-79-2100

ENGINE PERFORMANCE DETERIORATION



CS-79-2094

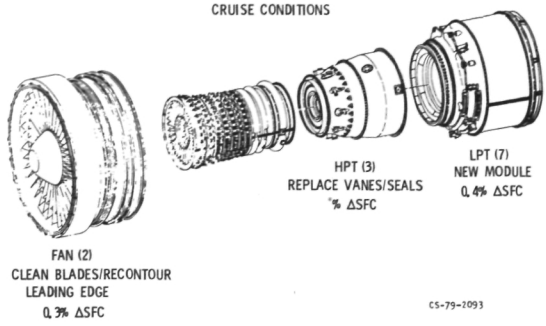
ENGINE DETERIORATION DATA SOURCES

HISTORICAL INFORMATION
- IN-FLIGHT RECORDINGS/GROUND CHECK-OUT 1/3 OF WORLD FLEET
- SELECTED USED PARTS

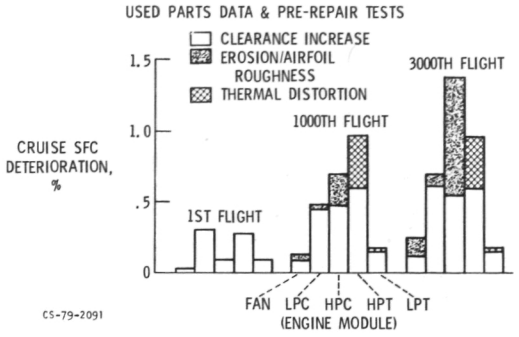
SPECIAL ENGINE TESTS
- OVERALL PERFORMANCE
- MODULAR REPLACEMENT/REFURBISHMENT

CS-79-2080

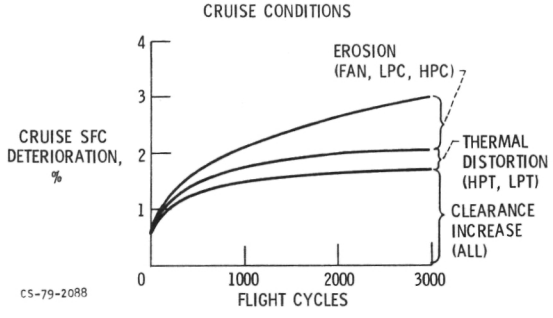
CF6 MODULE REPLACEMENT/REFURBISHMENT TEST RESULTS



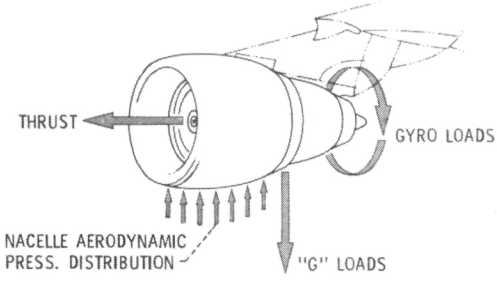
JT9D MODULAR PERFORMANCE DETERIORATION RESULTS



JT9D PERFORMANCE DETERIORATION BY DAMAGE MECHANISM

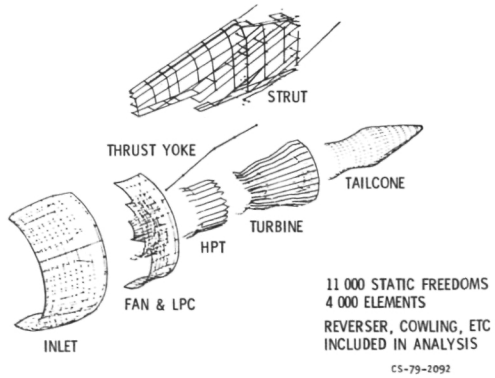


JT9D EXTERNAL APPLIED LOADS AND REACTIONS



- NACELLE AERODYNAMIC LOADS
- INERTIA LOADS

JT9D/747 PROPULSION SYSTEM STRUCTURAL MODEL



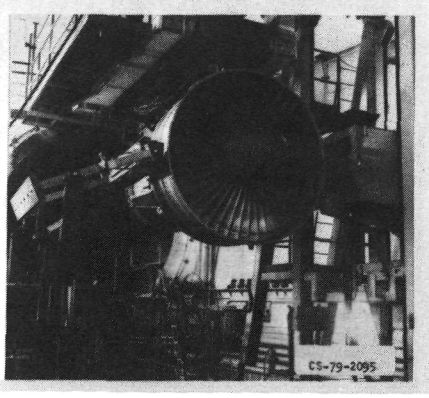
PROPULSION SYSTEM LOADS ANALYSIS RESULTS

STEADY STATE		
LOADS	AREA AFFECTED	% OF TOTAL ΔSFC LOSS, %
NACELLE AERODYNAMIC	ALL STAGES	87
INERTIA		
"G"	HPT STAGES	8
GYRO	FAN STAGE	5

DYNAMIC
NO SIGNIFICANT CHANGE FROM STEADY STATE

CS-79-2089

JT9D LOAD TEST PROGRAM



JT9D AERODYNAMIC LOAD TEST PROGRAM

SIMULATE STEADY STATE AERODYNAMIC LOADS DURING ENGINE PERFORMANCE TESTS

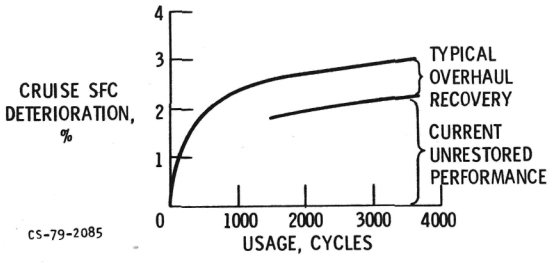
USE X-RAYS & LASER PROXIMITY PROBES TO DETERMINE CHANGES IN TIP CLEARANCES DURING TEST

MEASURE ENGINE PERFORMANCE TO DETERMINE ENGINE & MODULE PERFORMANCE DETERIORATION

CS-79-2081

AVERAGE ENGINE PERFORMANCE DETERIORATION TRENDS

JT9D & CF6



CS-79-2085

ENGINE DIAGNOSTICS PROGRAM OUTPUT

CURRENT ENGINES

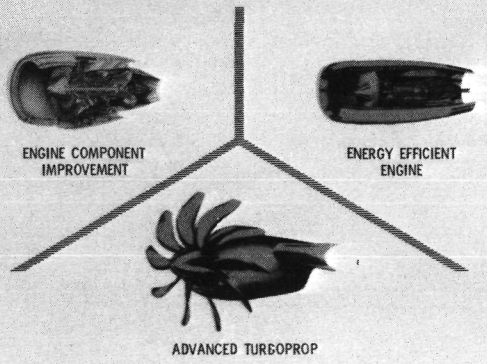
- PROVIDE INDUSTRY WITH DATA NECESSARY TO ACCOMPLISH COST EFFECTIVE ENGINE PERFORMANCE RESTORATION
- MAGNITUDE & LOCATION OF PERFORMANCE DETERIORATION
- IMPROVED MODULAR PERFORMANCE ANALYSIS

DERIVATIVE & FUTURE ENGINES

- PROVIDE DESIGN TOOLS FOR IMPROVED PERFORMANCE RETENTION
  - IDENTIFY UNIQUE PERFORMANCE DETERIORATION MECHANISMS
  - USAGE RELATED PERFORMANCE DETERIORATION MODELS

CS-79-2090

ACEE PROPULSION PROJECTS



ENERGY EFFICIENT ENGINE PROJECT

OBJECTIVE

- PROVIDE AN ADVANCED-TECHNOLOGY BASE FOR A NEW GENERATION OF FUEL-CONSERVATIVE TURBOFAN ENGINES FOR COMMERCIAL TRANSPORT USE

APPROACH

- DEVELOP ADVANCED COMPONENT TECHNOLOGIES
- EVALUATE INTEGRATED SYSTEM PERFORMANCE
- DEMONSTRATE TECHNOLOGY READINESS BY 1983

CS-79-2066

ENERGY EFFICIENT ENGINE PROJECT
PROPULSION SYSTEM DESIGN GOALS

REDUCE FUEL USAGE
- 12% SPECIFIC FUEL CONSUMPTION (SFC)
- 50% PERFORMANCE DETERIORATION RATE

IMPROVE OPERATING COSTS
- 5% DIRECT OPERATING COST (DOC)

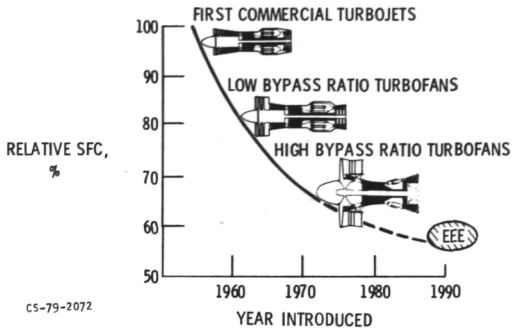
} RELATIVE TO CURRENT ENGINES (JT9D-7A/CF6-50C)

MEET FUTURE ENVIRONMENTAL REGULATIONS

NOISE	FAR-36 (1978)
EMISSIONS	EPA-1981

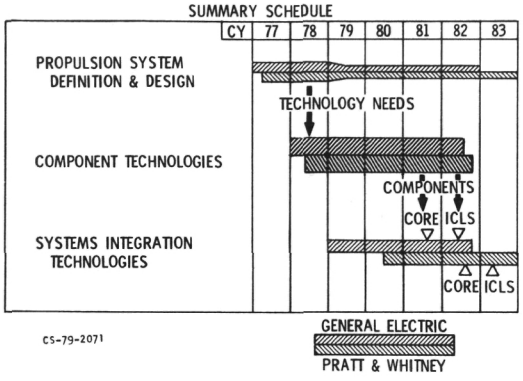
CS-79-2068

IMPROVEMENTS IN TURBOFAN FUEL EFFICIENCY



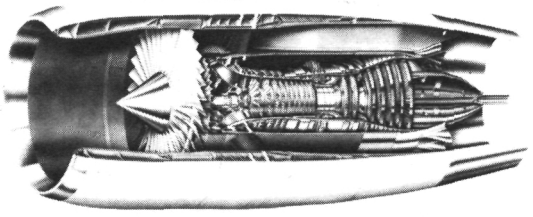
CS-79-2072

ENERGY EFFICIENT ENGINE PROJECT
SUMMARY SCHEDULE



CS-79-2071

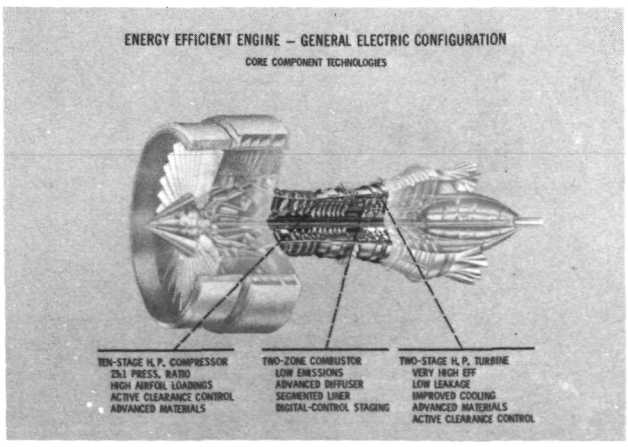
ENERGY EFFICIENT ENGINE CONFIGURATION
GENERAL ELECTRIC

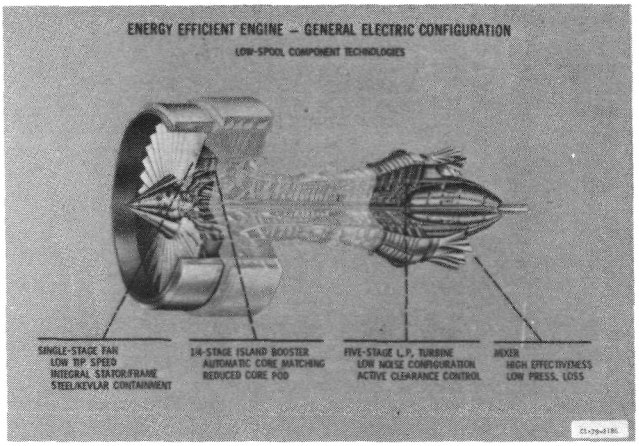


CYCLE CHARACTERISTICS OF GENERAL ELECTRIC'S ENGINES AT MAX CRUISE CONDITIONS

	EEE	CF6-50C
EXHAUST CONFIGURATION	MIXED	SEPARATE
BYPASS RATIO	6.9	4.3
FAN PRESS. RATIO	1.61	1.72
COMPRESSOR PRESS. RATIO	22.6	12.9
OVERALL PRESS. RATIO	36.1	32.0
TURBINE TEMP, °F		
HOT-DAY TAKEOFF	2450	2400
MAX CRUISE	2170	2080
TAKEOFF THRUST, SLS-lb	36 500	50 250
INSTALLED SFC, lbm/hr/lbf	0.572	0.666
	Δ = 14.2%	

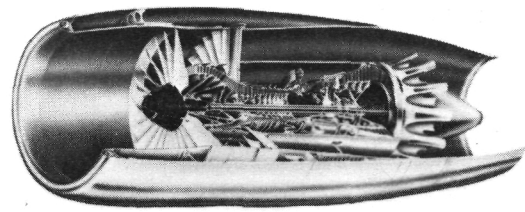
CS-79-2065





ENERGY EFFICIENT ENGINE CONFIGURATION

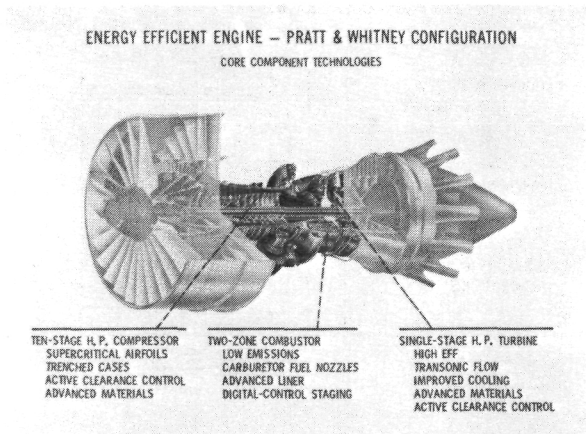
PRATT & WHITNEY

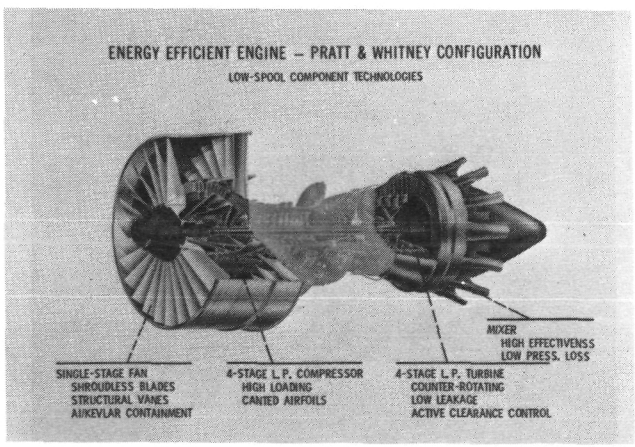


CYCLE CHARACTERISTICS OF
PRATT & WHITNEY'S ENGINES
AT MAX CRUISE CONDITIONS

	EEE	JT9D-7A
EXHAUST CONFIGURATION	MIXED	SEPARATE
BYPASS RATIO	6.6	5.1
FAN PRESS. RATIO	1.71	1.58
COMPRESSOR PRESS. RATIO	13.9	10.0
OVERALL PRESS. RATIO	37.4	25.4
TURBINE TEMP, °F		
HOT-DAY TAKEOFF	2495	2300
MAX CRUISE	2200	2000
TAKEOFF THRUST, SLS-lb	41 115	46 300
INSTALLED SFC, lbm/hr/lbf	0.576	0.677
	Δ = -14.9%	

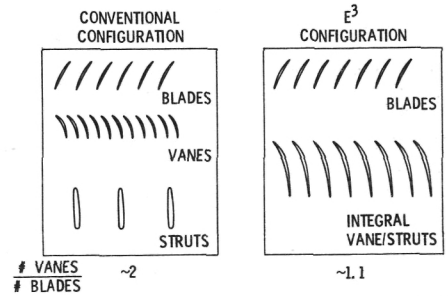
CS-79-2067





ENERGY EFFICIENT ENGINE – GENERAL ELECTRIC

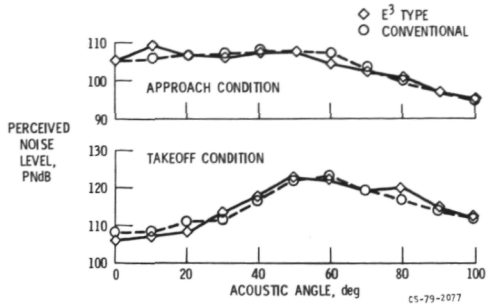
FAN-FRAME ACOUSTIC CONFIGURATIONS



CS-79-2078

ENERGY EFFICIENT ENGINE – GENERAL ELECTRIC

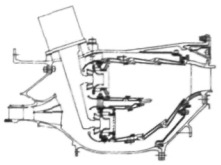
FAN-FRAME ACOUSTIC TEST RESULTS



ENERGY EFFICIENT ENGINE - GENERAL ELECTRIC

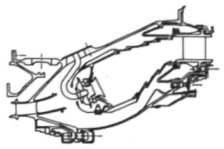
COMBUSTOR CONFIGURATIONS

DOUBLE-ANNULAR COMBUSTOR



- CLEANER BURNING
- MORE COMPLEX

SINGLE-ANNULAR COMBUSTOR

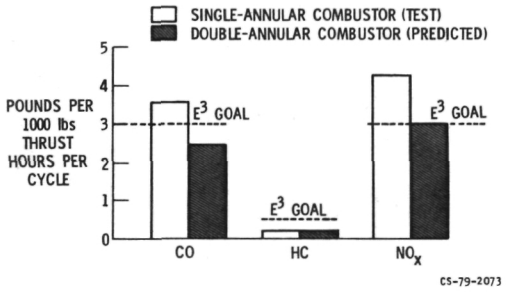


- LOWER COST
- LESS WEIGHT

CS-79-2070

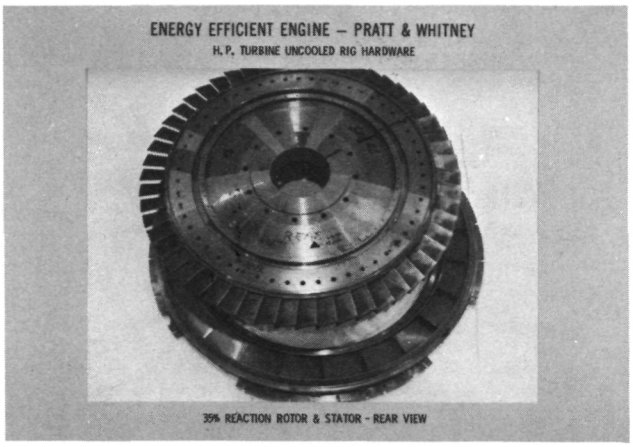
ENERGY EFFICIENT ENGINE – GENERAL ELECTRIC

COMBUSTOR EMISSION CHARACTERISTICS; 4% IDLE THRUST



ENERGY EFFICIENT ENGINE – PRATT & WHITNEY

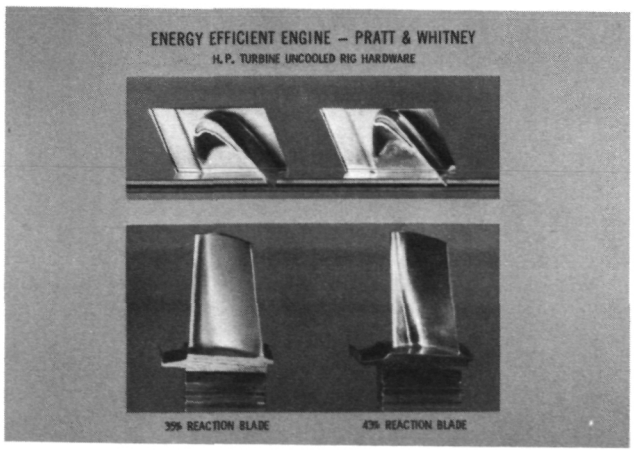
H.P. TURBINE UNCOOLED RIG HARDWARE



35% REACTION ROTOR & STATOR - REAR VIEW

ENERGY EFFICIENT ENGINE – PRATT & WHITNEY

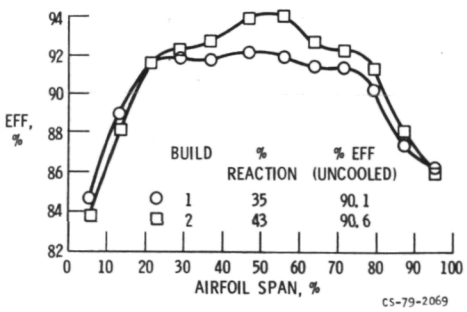
H.P. TURBINE UNCOOLED RIG HARDWARE



35% REACTION BLADE 43% REACTION BLADE

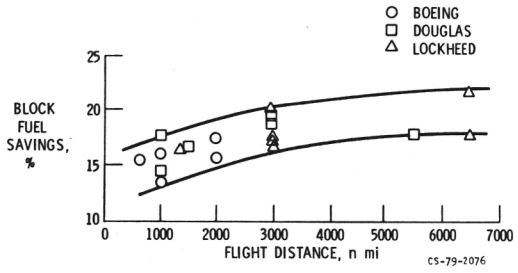
ENERGY EFFICIENT ENGINE – PRATT & WHITNEY

H. P. TURBINE UNCOOLED-RIG TEST RESULTS



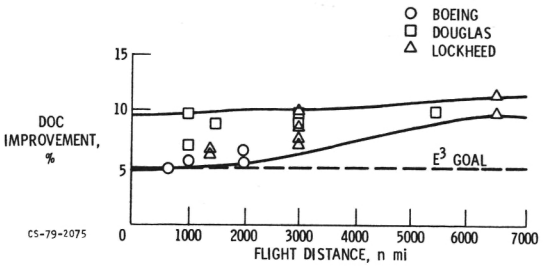
POTENTIAL FUEL SAVINGS OF ENERGY EFFICIENT ENGINES

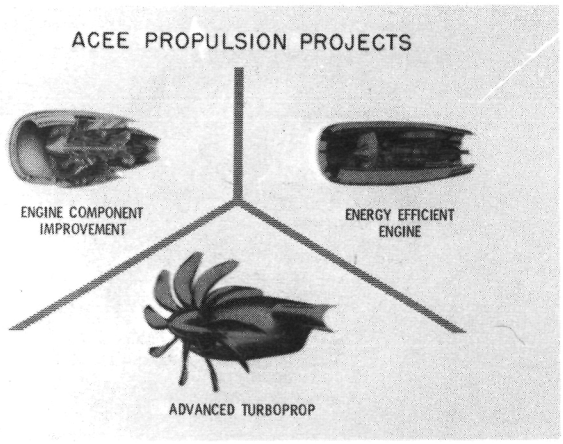
RELATIVE TO THE SAME AIRCRAFT WITH SCALED JT9D-7A OR CF6-50C



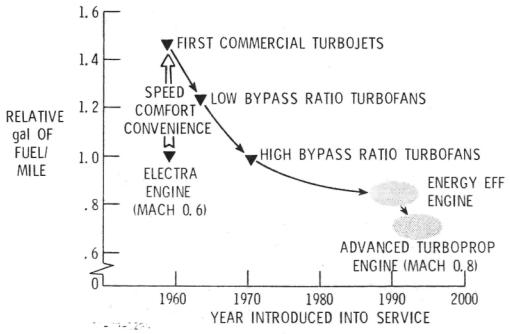
POTENTIAL DOC IMPROVEMENTS OF ENERGY EFFICIENT ENGINES

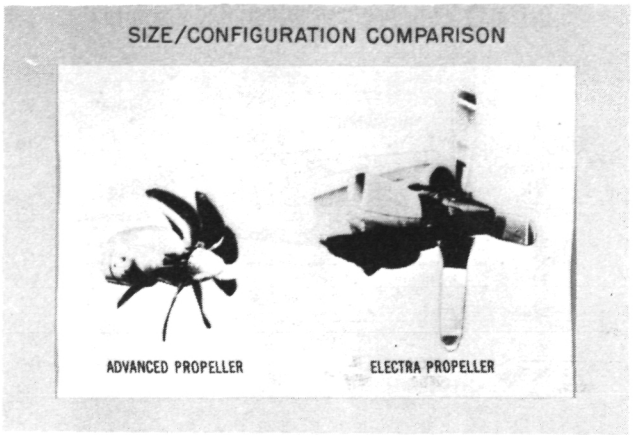
RELATIVE TO THE SAME AIRCRAFT WITH SCALED JT9D-7A OR CF6-50C

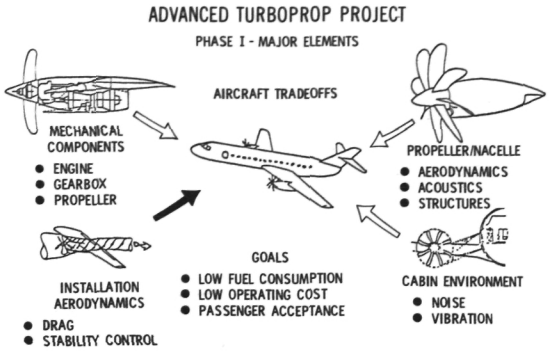


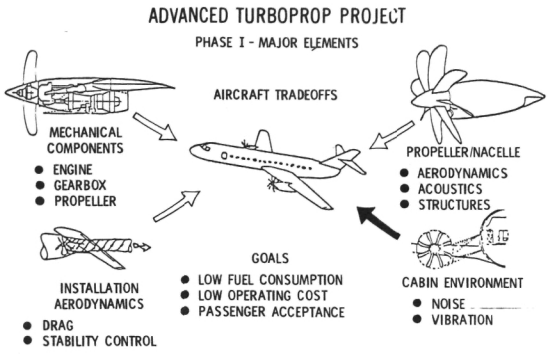


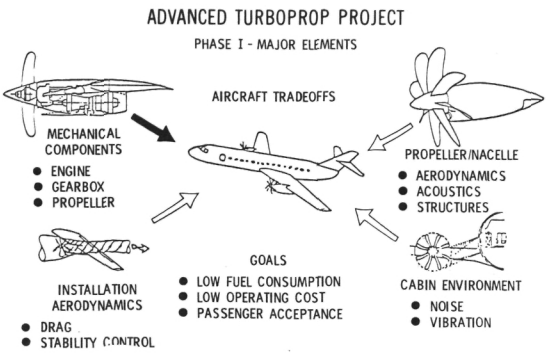
PROPULSION SYSTEM RELATIVE FUEL CONSUMPTION



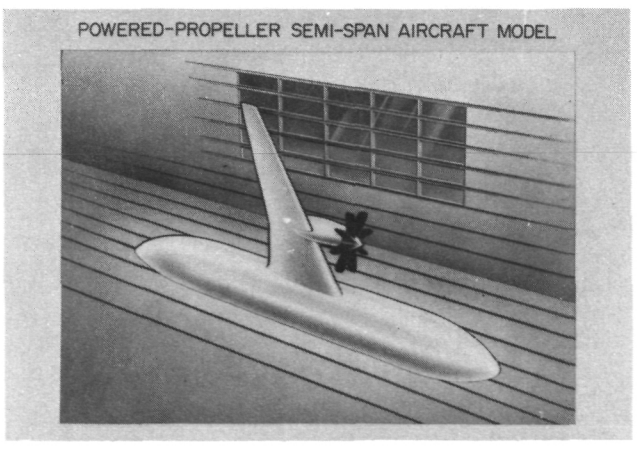

SIZE/CONFIGURATION COMPARISON
ADVANCED PROPELLER
ELECTRA PROPELLER


ADVANCED TURBOPROP PROJECT
PHASE I - MAJOR ELEMENTS
AIRCRAFT TRADEOFFS
MECHANICAL COMPONENTS
ENGINE
GEARBOX
PROPELLER
PROPELLER/NACELLE
AERODYNAMICS
ACOUSTICS
STRUCTURES
INSTALLATION AERODYNAMICS
DRAG
STABILITY CONTROL
GOALS
LOW FUEL CONSUMPTION
LOW OPERATING COST
PASSENGER ACCEPTANCE
CABIN ENVIRONMENT
NOISE
VIBRATION


ADVANCED TURBOPROP PROJECT
PHASE I - MAJOR ELEMENTS
AIRCRAFT TRADEOFFS
MECHANICAL COMPONENTS
ENGINE
GEARBOX
PROPELLER
PROPELLER/NACELLE
AERODYNAMICS
ACOUSTICS
STRUCTURES
INSTALLATION AERODYNAMICS
DRAG
STABILITY CONTROL
GOALS
LOW FUEL CONSUMPTION
LOW OPERATING COST
PASSENGER ACCEPTANCE
CABIN ENVIRONMENT
NOISE
VIBRATION


ADVANCED TURBOPROP PROJECT
PHASE I - MAJOR ELEMENTS
AIRCRAFT TRADEOFFS
MECHANICAL COMPONENTS
ENGINE
GEARBOX
PROPELLER
PROPELLER/NACELLE
AERODYNAMICS
ACOUSTICS
STRUCTURES
INSTALLATION AERODYNAMICS
DRAG
STABILITY CONTROL
GOALS
LOW FUEL CONSUMPTION
LOW OPERATING COST
PASSENGER ACCEPTANCE
CABIN ENVIRONMENT
NOISE
VIBRATION

FLIGHT TEST CONCEPT FOR MODEL PROPELLER ACOUSTICS


POWERED-PROPELLER SEMI-SPAN AIRCRAFT MODEL

RELIABILITY AND MAINTENANCE COST STUDY

CONTRACT NAS3-20057 (DETROIT DIESEL ALLISON)

1960 ERA TURBOPROP MAINTENANCE COSTS HIGHER THAN JT8D - DIFFERENCE MAINLY IN CORE ENGINE

ADVANCED TURBOPROP CAN BE COMPETITIVE WITH ADVANCED TURBOFAN

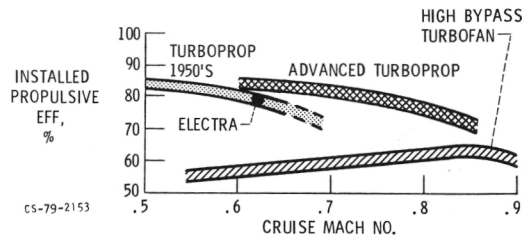
EQUAL CORE COSTS

PROPELLER & GEARBOX GREATLY IMPROVED

- ELIMINATE SCHEDULED OVERHAULS
- USE MODULAR CONSTRUCTION
- SIMPLER, MORE RELIABLE DESIGN

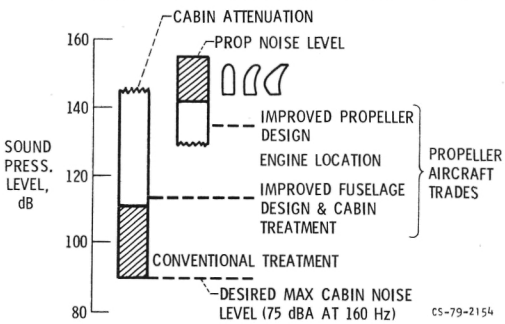
CS-79-2152

INSTALLED PROPULSIVE EFFICIENCY AT CRUISE



CABIN NOISE

ADVANCED TURBOPROP-POWERED AIRCRAFT AT MACH 0.80 CRUISE



ADVANCED PROPELLER TECHNOLOGY PROGRAM

PHASE I

DESIGN MATRIX OF EIGHT 2-ft DIAM WIND TUNNEL MODELS

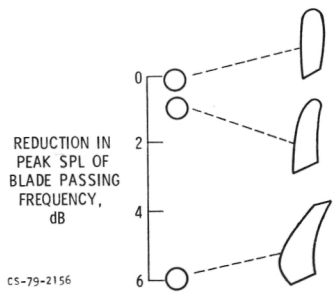
NO. OF BLADES	8 OR 10
SWEEP AT BLADE TIP, deg	0 TO 60
TIP SPEED, ft/sec (RELATIVE TIP MACH NO.)	600 TO 800 (1.0 TO 1.15)
POWER LOADING, hp/ft^2 (RELATIVE DIAM)	26 TO 37.5 (1.2 TO 1.0)

USE DATA TO UPGRADE AERO, ACOUSTIC, & STRUCTURAL ANALYSIS & PREDICTION PROGRAMS

CS-79-2155

NOISE COMPARISON OF ADVANCED PROPELLER MODELS

M_0 = 0.8 DESIGN CONDITIONS; LEWIS 8 x 6 WIND TUNNEL



ADVANCED TURBOPROP PROJECT

OBJECTIVE

DEVELOP TECHNOLOGY FOR EFFICIENT, RELIABLE, & ACCEPTABLE OPERATION OF ADVANCED TURBOPROP-POWERED AIRCRAFT AT CRUISE SPEEDS UP TO MACH 0.8 & ALTITUDES OF 30 000 ft & HIGHER

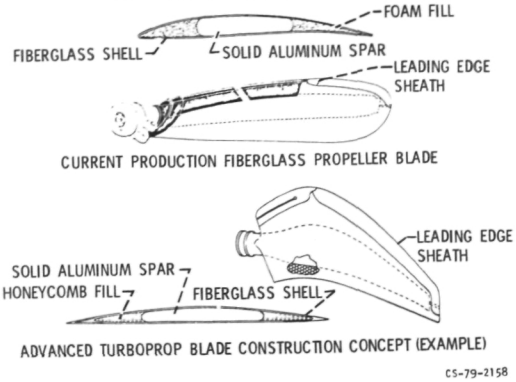
GOALS

MIN. 15% FUEL SAVINGS
MIN. 5% DOC IMPROVEMENT
} RELATIVE TO TURBOFAN ENGINES WITH SAME LEVEL OF CORE TECHNOLOGY

CABIN COMFORT (NOISE & VIBRATION) SAME AS CURRENT TURBOFAN-POWERED AIRCRAFT

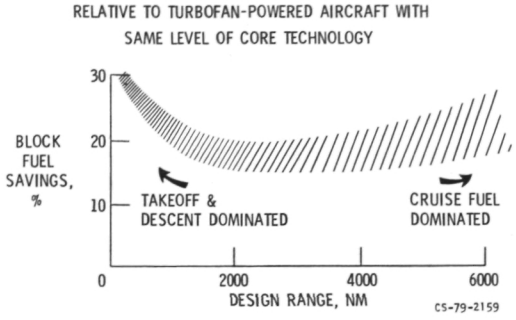
CS-79-2157

BLADE FABRICATION COMPARISON



CS-79-2158

TREND OF POTENTIAL FUEL SAVINGS FOR ADVANCED TURBOPROP-POWERED AIRCRAFT



CS-79-2159

ADVANCED TURBOPROP

PHASE I - ENABLING TECHNOLOGY

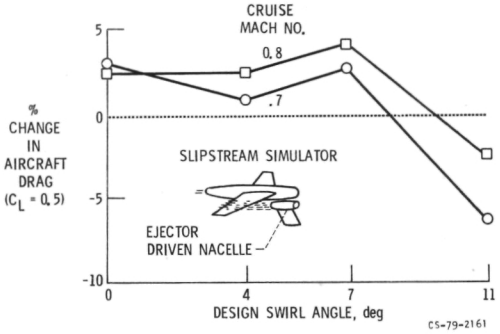
SUBSCALE COMPONENTS
- PROPELLER DESIGN PARAMETERS
- FUSELAGE NOISE ATTENUATION
- AIRFRAME INTERACTIONS

FUTURE PHASES

LARGE-SCALE COMPONENTS - DEVELOPMENT & VERIFICATION
- PROPELLER FABRICATION
- PROPELLER AERO/ACOUSTIC/STRUCTURAL SCALING VERIFICATION
- FUSELAGE SEGMENTS/CABIN ENVIRONMENT
- ADVANCED GEARBOX & PITCH CHANGE SYSTEM
- AIRFRAME INTERACTIONS
- INSTALLED PERFORMANCE
- OPERATIONAL EFFECTS
- ADVANCED ENGINE/GEARBOX/PITCH CHANGE SYSTEM PERFORMANCE

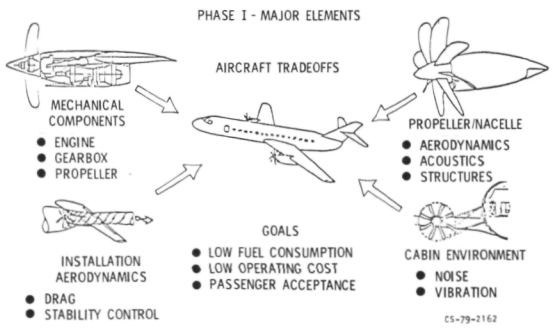
CS-79-2160

SIMULATED SLIPSTREAM EFFECT ON AIRCRAFT CRUISE DRAG



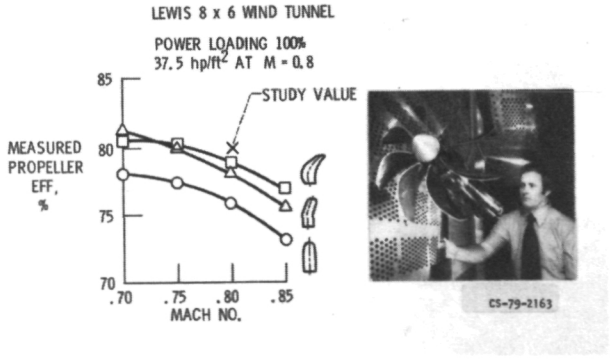
CS-79-2161

ADVANCED TURBOPROP PROJECT



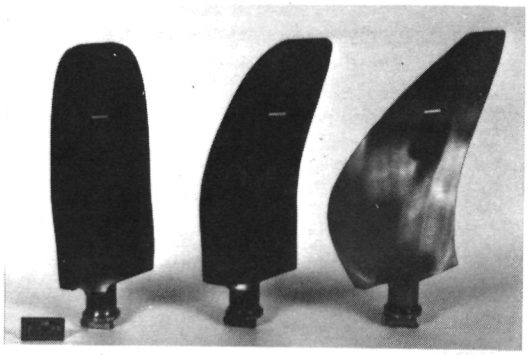
CS-79-2162

PROPELLER MODEL EFFICIENCY

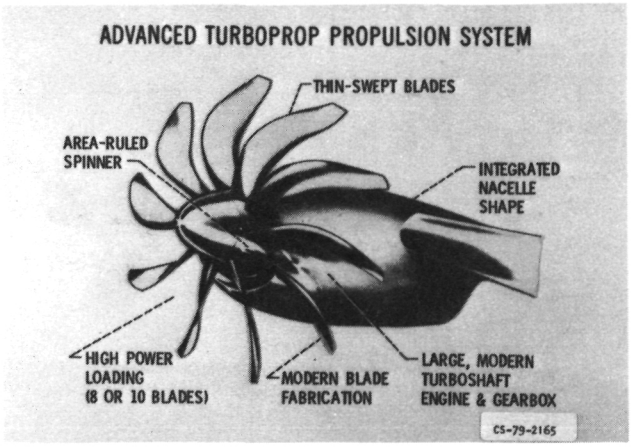


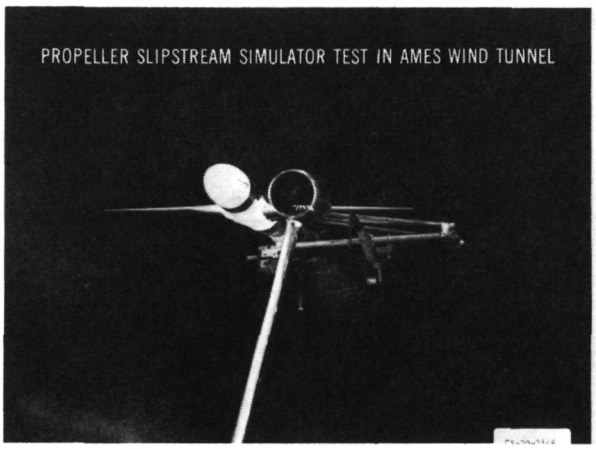
CS-79-2163

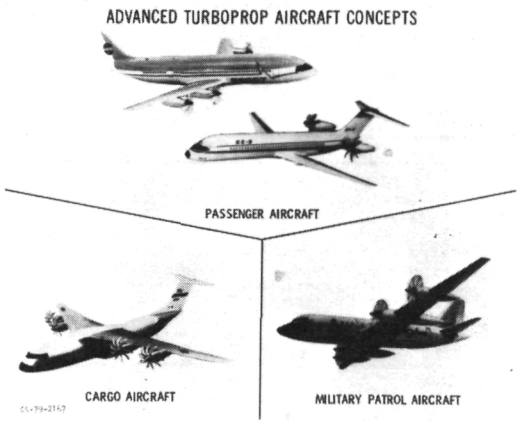
MODEL PROPELLER BLADES

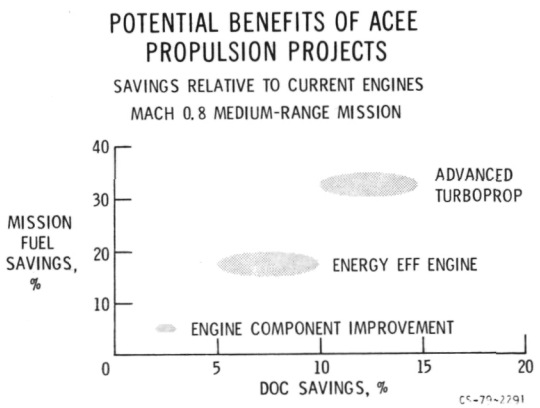


SWEEP 0° 30° 45° C5-79-2164







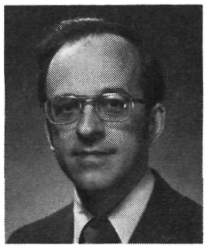


D2

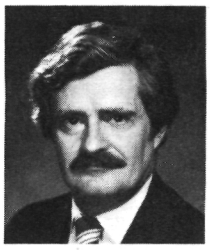
II. EMISSION REDUCTION

Donald A. Petrash, Chairman
Larry A. Diehl
Robert E. Jones
Edward J. Mularz

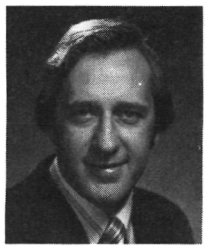
DONALD A. PETRASH is Chief of the Combustion and Pollution Research Branch, Airbreathing Engines Division, at NASA Lewis. He began his Lewis career in 1954 after receiving a B.S. degree in physics and an M.S. degree in mathematics from John Carroll University. He has specialized in turbine aerodynamics, in dynamics and thermodynamics of fluids in weightlessness, and in combustion research for gas turbine propulsion systems.



LARRY A. DIEHL is Head of the Combustion Fundamentals Section, Airbreathing Engines Division, at NASA Lewis, whose staff he joined in 1969. He was awarded a B.S. degree in aeronautical engineering in 1965 by the University of Detroit and a Ph.D. degree in aeronautical and astronautical engineering by Ohio State University in 1970. He has specialized in basic and applied research in fundamentals of combustion, formation of pollutant emissions, and advanced combustor concepts that incorporate improved performance and reduced pollutant emissions.



ROBERT E. JONES became a member of the NASA Lewis staff in 1955. He earned a B.S. degree in chemical engineering from MIT in 1954 and an M.S. degree in 1955. As Head of the Combustor Technology Section, Airbreathing Engines Division, he is concerned with combustor research to evolve new design concepts that attack the problems of emissions, high-pressure performance, and durability as well as with internal combustor flows and mixing.



EDWARD J. MULARZ joined the U.S. Army Propulsion Laboratory at NASA Lewis in 1971 after receiving a B.S. degree in mechanical engineering from the University of Detroit in 1966 and a Ph.D. degree in mechanical engineering from Northwestern University in 1971. As a member of the Combustion Fundamentals Section, Airbreathing Engines Division, he has specialized in designing advanced-technology combustors with low-pollutant characteristics and improved high-pressure-performance capability. He is currently Project Manager of the NASA Stratospheric Cruise Emission Reduction Program and is a member of the ASME Combustion and Fuels Committee and the AIAA.

CLEAN AIR CHRONOLOGY

1960'S	AIR QUALITY - A NATIONAL ISSUE
1970	CONGRESS AMENDS CLEAN AIR ACT TO INCLUDE POLLUTION FROM AIRCRAFT ENGINES
1971	NASA INITIATED POLLUTION REDUCTION TECHNOLOGY PROGRAM
1973	EPA ISSUES POLLUTANT EMISSION STANDARDS TO BECOME EFFECTIVE IN 1979
1978	EPA ISSUES NPRM PROPOSING REVISIONS TO THE POLLUTANT EMISSIONS STANDARDS

CS-79-1755

GASEOUS EMISSION STANDARDS

	ENGINE CLASS	POLLUTANT* HC	CO	NO_x
T1	TURBOJET/TURBOFAN LESS THAN 8000 lb THRUST	1.6	9.4	3.7
T2	TURBOJET/TURBOFAN GREATER THAN 8000 lb THRUST	.8	4.3	3.0
T3	P & W JT3D	.8	4.3	3.0
T4	P & W JT8D	.8	4.3	3.0
T5	TURBOJET/TURBOFAN ENGINES FOR SUPERSONIC AIRCRAFT	3.9	30.1	9.0
P2	TURBOPROP ENGINES	4.9	26.8	12.9

*T STANDARDS AS lb/1000 lb THRUST-hr/CYCLE
P STANDARDS AS lb/1000 hp-hr/CYCLE

CS-79-1758

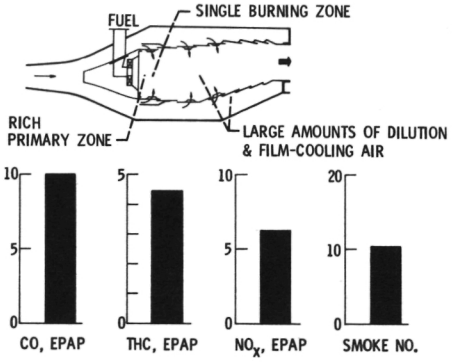
NASA'S EMISSION REDUCTION RESEARCH AND TECHNOLOGY PROGRAM

IMPLEMENT A NEAR TERM TECHNOLOGY PROGRAM TO ACHIEVE LARGE & IMMEDIATE REDUCTIONS IN POLLUTANT LEVELS

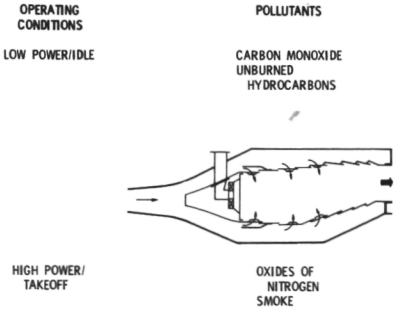
IMPLEMENT A LONG TERM RESEARCH & TECHNOLOGY PROGRAM WITH THE GOAL OF ACHIEVING MIN. POLLUTANT EMISSION LEVELS

CS-79-1743

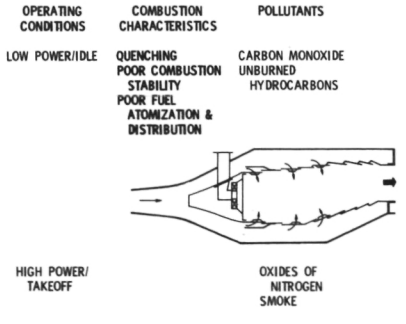
CURRENT COMBUSTORS



COMBUSTOR EMISSIONS

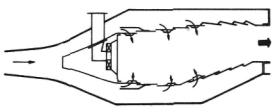


COMBUSTOR EMISSIONS



COMBUSTOR EMISSIONS

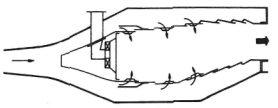
OPERATING CONDITIONS	COMBUSTION CHARACTERISTICS	POLLUTANTS	REDUCTION TECHNIQUES
LOW POWER/IDLE	QUENCHING POOR COMBUSTION STABILITY POOR FUEL ATOMIZATION & DISTRIBUTION	CARBON MONOXIDE UNBURNED HYDROCARBONS	INCREASE RESIDENCE TIME REDUCE FLOW VELOCITY DELAY MIXING INCREASE EQUIV RATIO IMPROVE FUEL ATOMIZATION & DISTRIBUTION



HIGH POWER/ TAKEOFF		OXIDES OF NITROGEN SMOKE	

COMBUSTOR EMISSIONS

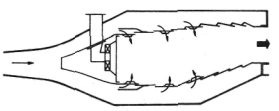
OPERATING CONDITIONS	COMBUSTION CHARACTERISTICS	POLLUTANTS	REDUCTION TECHNIQUES
LOW POWER/IDLE	QUENCHING POOR COMBUSTION STABILITY POOR FUEL ATOMIZATION & DISTRIBUTION	CARBON MONOXIDE UNBURNED HYDROCARBONS	INCREASE RESIDENCE TIME REDUCE FLOW VELOCITY DELAY MIXING INCREASE EQUIV RATIO IMPROVE FUEL ATOMIZATION & DISTRIBUTION



HIGH POWER/ TAKEOFF	EXCESS RESIDENCE TIME HIGH FLAME TEMP POOR LOCAL FUEL DISTRIBUTION	OXIDES OF NITROGEN SMOKE	

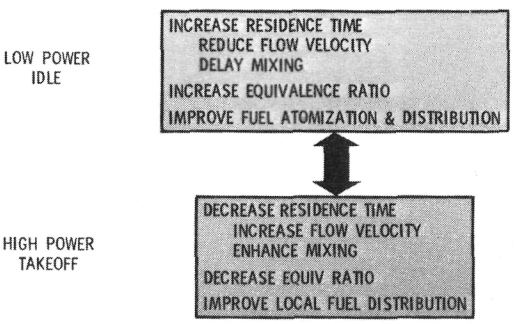
COMBUSTOR EMISSIONS

OPERATING CONDITIONS	COMBUSTION CHARACTERISTICS	POLLUTANTS	REDUCTION TECHNIQUES
LOW POWER/IDLE	QUENCHING POOR COMBUSTION STABILITY POOR FUEL ATOMIZATION & DISTRIBUTION	CARBON MONOXIDE UNBURNED HYDROCARBONS	INCREASE RESIDENCE TIME REDUCE FLOW VELOCITY DELAY MIXING INCREASE EQUIV RATIO IMPROVE FUEL ATOMIZATION & DISTRIBUTION



HIGH POWER/ TAKEOFF	EXCESS RESIDENCE TIME HIGH FLAME TEMP POOR LOCAL FUEL DISTRIBUTION	OXIDES OF NITROGEN SMOKE	DECREASE RESIDENCE TIME INCREASE FLOW VELOCITY ENHANCE MIXING DECREASE EQUIV RATIO IMPROVE LOCAL FUEL DISTRIBUTION

EMISSION REDUCTION PROBLEM



NEAR TERM EMISSION REDUCTION PROGRAM

OBJECTIVES

TO INVESTIGATE NEW COMBUSTOR CONCEPTS WITH POTENTIAL FOR SIGNIFICANTLY LOWER EMISSION LEVELS

TO MEASURE THE EMISSIONS REDUCTION BY ENGINE TEST

CS-79-1746

NEAR TERM EMISSION REDUCTION PROGRAM

APPROACH

SCREEN LOW EMISSION COMBUSTOR CONCEPTS

REFINE BEST LOW EMISSION COMBUSTORS

MEASURE EMISSION REDUCTION BY ENGINE TEST

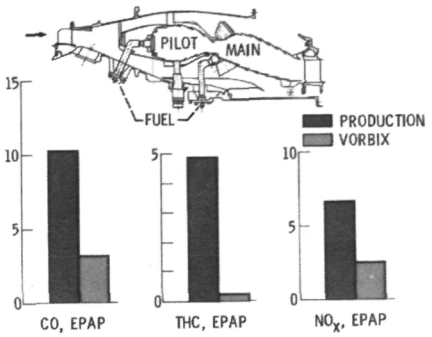
CS-79-1745

NEAR TERM EMISSION REDUCTION PROGRAM SCOPE

ENGINE CLASS	MANUFACTURER	ENGINE
P2	DETROIT-DIESEL-ALLISON	501-D22-A
T1	GARRETT AIRESEARCH	TFE-731-2
T4	PRATT & WHITNEY	JT8D-17
T2	PRATT & WHITNEY	JT9D-7
T2	GENERAL ELECTRIC	CF6-50

CS-79-1747

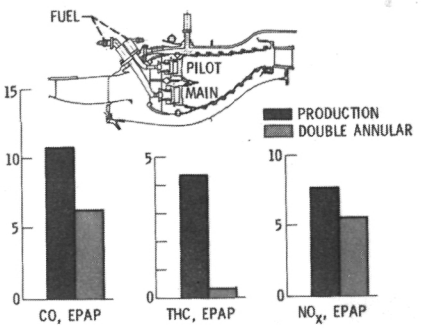
VORBIX COMBUSTOR CONCEPT FOR JT9D-7 ENGINE



PROTOTYPE VORBIX COMBUSTOR

CS-79-2148

DOUBLE/ANNULAR COMBUSTOR FOR CF6-50 ENGINE



PROTOTYPE DOUBLE ANNULAR COMBUSTOR

CS-79-1759

SIGNIFICANT ACHIEVEMENTS

ALL POLLUTANTS WERE SIGNIFICANTLY REDUCED

COMBUSTORS OPERATED ENGINES TO FULL POWER & MET OR CLOSELY APPROACHED REQUIRED ACCELERATION TIMES

COMBUSTOR PERFORMANCE WAS GENERALLY EQUAL TO OR BETTER THAN PRODUCTION COMBUSTORS CONSIDERING LIMITED PROGRAM SCOPE

CS-79-1741

AREAS REQUIRING FURTHER WORK

FUEL SYSTEM COKING

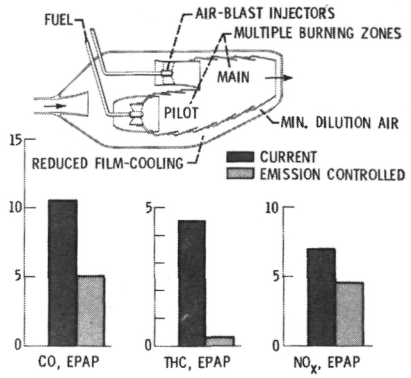
DURABILITY

ALTITUDE RELIGHT/GROUND START

PATTERN FACTOR

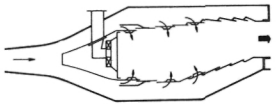
CS-79-1742

EMISSION CONTROLLED COMBUSTORS



COMBUSTOR EMISSIONS

OPERATING CONDITIONS	COMBUSTION CHARACTERISTICS	POLLUTANTS	REDUCTION TECHNIQUES
LOW POWER/IDLE	QUENCHING POOR COMBUSTION STABILITY POOR FUEL ATOMIZATION & DISTRIBUTION	CARBON MONOXIDE UNBURNED HYDROCARBONS	INCREASE RESIDENCE TIME REDUCE FLOW VELOCITY DELAY MIXING INCREASE EQUIV RATIO IMPROVE FUEL ATOMIZATION & DISTRIBUTION
HIGH POWER/ TAKEOFF	EXCESS RESIDENCE TIME HIGH FLAME TEMP POOR LOCAL FUEL DISTRIBUTION	OXIDES OF NITROGEN SMOKE	DECREASE RESIDENCE TIME INCREASE FLOW VELOCITY ENHANCE MIXING DECREASE EQUIV RATIO IMPROVE LOCAL FUEL DISTRIBUTION



NEAR TERM IDLE EMISSIONS REDUCTION PROGRAM OBJECTIVE

TO INVESTIGATE NEW COMBUSTOR CONCEPTS WITH POTENTIAL FOR SIGNIFICANTLY LOWER ENGINE IDLE EMISSIONS LEVELS

CS-79-1750

NEAR TERM IDLE EMISSIONS REDUCTION PROGRAM APPROACH

INVESTIGATE COMBUSTOR CONCEPTS THAT HAVE NONCONVENTIONAL DESIGN FEATURES

TESTING CONFINED TO TYPICAL IDLE CONDITIONS

FOCUS ON PILOT STAGE OF A MULTISTAGE COMBUSTOR

CS-79-1744

COMBUSTOR DESIGN CHARACTERISTICS

HOT WALL COMBUSTOR
- REFRACTORY COATED SURFACES TO MINIMIZE WALL QUENCHING

RECUPERATIVE COOLING COMBUSTOR
- PREHEATED PRIMARY ZONE AIR TO INCREASE COMBUSTION REACTION RATES

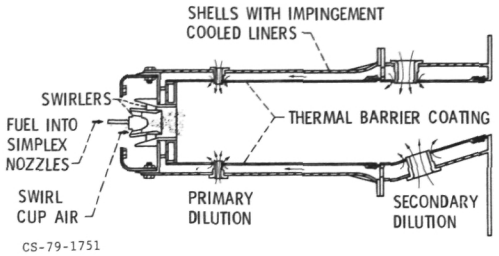
CATALYTIC CONVERTER COMBUSTOR
- PRECOMBUSTION FOLLOWED BY CATALYTIC CLEANUP FOR RAPID CONSUMPTION OF RESIDUAL CO & HC

ALL COMBUSTORS
- IMPINGEMENT COOLED LINERS
- AIR BLAST FUEL INJECTORS
- NEAR STOICHIOMETRIC PRIMARY ZONE EQUIVALENCE RATIO AT IDLE CONDITIONS

CS-79-1757

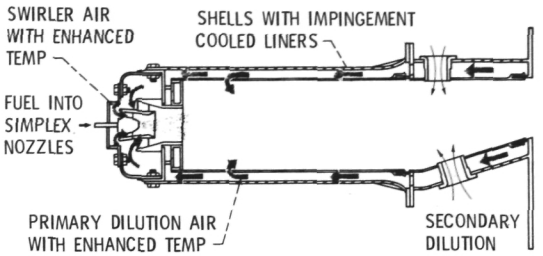
HOT WALL COMBUSTOR

CONCEPT NO. 1



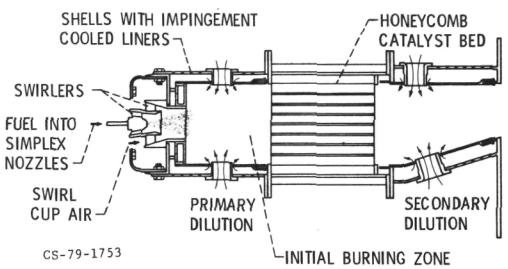
RECUPERATIVE COOLING COMBUSTOR

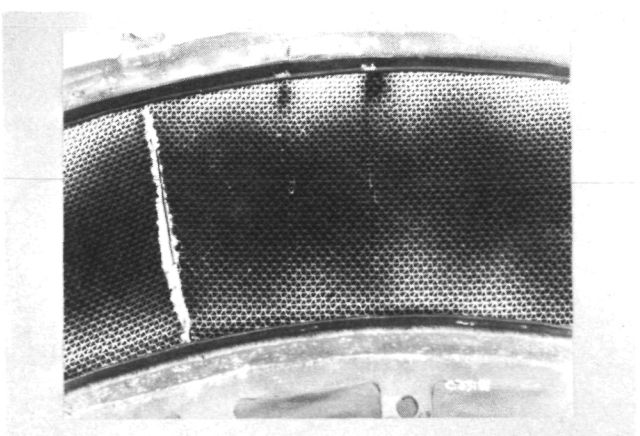
CONCEPT NO. 2

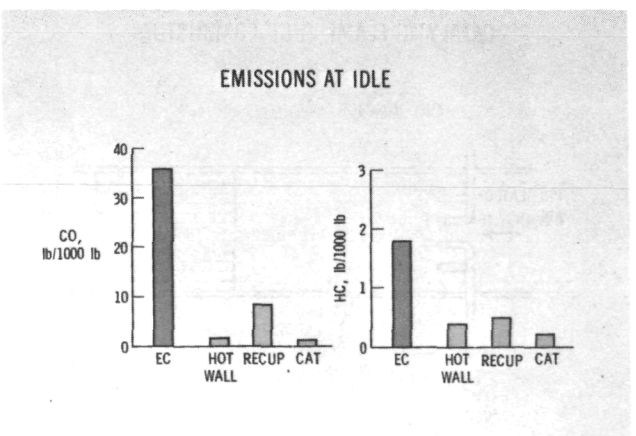


CATALYTIC CONVERTER COMBUSTOR

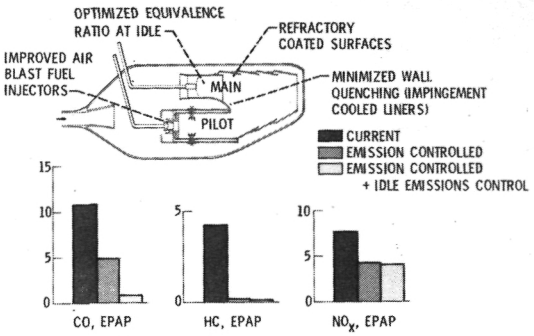
CONCEPT NO. 3





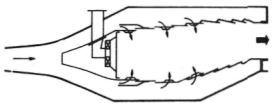


PROJECTED ENGINE EMISSIONS INCORPORATING IDLE EMISSIONS CONTROL TECHNOLOGY



COMBUSTOR EMISSIONS

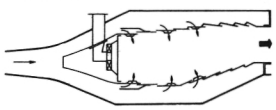
OPERATING CONDITIONS	COMBUSTION CHARACTERISTICS	POLLUTANTS	REDUCTION TECHNIQUES
LOW POWER/IDLE	QUENCHING POOR COMBUSTION STABILITY POOR FUEL ATOMIZATION & DISTRIBUTION	CARBON MONOXIDE UNBURNED HYDROCARBONS	INCREASE RESIDENCE TIME REDUCE FLOW VELOCITY DELAY MIXING INCREASE EQUIV RATIO IMPROVE FUEL ATOMIZATION & DISTRIBUTION



HIGH POWER/ TAKEOFF	EXCESS RESIDENCE TIME HIGH FLAME TEMP POOR LOCAL FUEL DISTRIBUTION	OXIDES OF NITROGEN SMOKE	DECREASE RESIDENCE TIME INCREASE FLOW VELOCITY ENHANCE MIXING DECREASE EQUIV RATIO IMPROVE LOCAL FUEL DISTRIBUTION

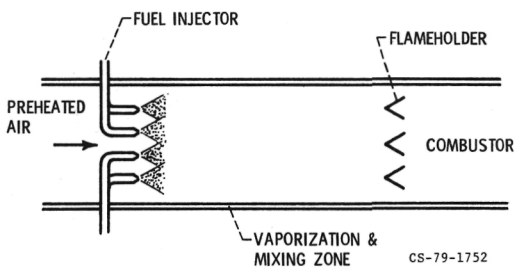
COMBUSTOR EMISSIONS

OPERATING CONDITIONS	COMBUSTION CHARACTERISTICS	POLLUTANTS	REDUCTION TECHNIQUES
LOW POWER/IDLE	QUENCHING POOR COMBUSTION STABILITY POOR FUEL ATOMIZATION & DISTRIBUTION	CARBON MONOXIDE UNBURNED HYDROCARBONS	INCREASE RESIDENCE TIME REDUCE FLOW VELOCITY DELAY MIXING INCREASE EQUIV RATIO IMPROVE FUEL ATOMIZATION & DISTRIBUTION

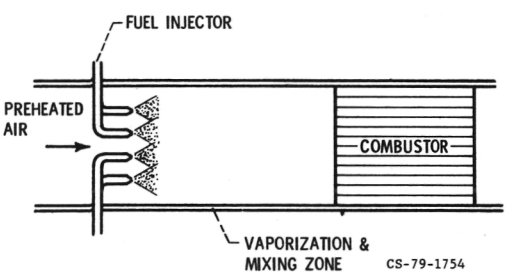


HIGH POWER/ TAKEOFF	EXCESS RESIDENCE TIME HIGH FLAME TEMP POOR LOCAL FUEL DISTRIBUTION	OXIDES OF NITROGEN SMOKE	DECREASE RESIDENCE TIME INCREASE FLOW VELOCITY ENHANCE MIXING DECREASE EQUIV RATIO IMPROVE LOCAL FUEL DISTRIBUTION PREVAPORIZE FUEL

PREMIX FLAME TUBE COMBUSTOR



CATALYTIC FLAME TUBE COMBUSTOR



FAR TERM EMISSION REDUCTION PROGRAM OBJECTIVE

TO EVOLVE THE TECHNOLOGY NEEDED FOR THE DEVELOPMENT OF COMBUSTORS WITH MIN. POLLUTANT LEVELS

CS-79-1748

FAR TERM EMISSION REDUCTION PROGRAM

APPROACH

CONDUCT BASIC & APPLIED RESEARCH

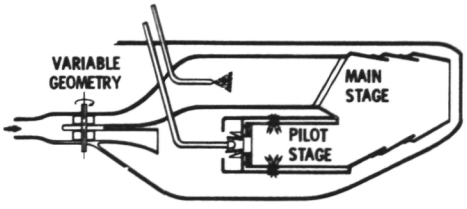
EMPHASIZE LEAN PREMIXED PREVAPORIZED & CATALYTIC TECHNIQUES

AS APPROPRIATE EVOLVE & EVALUATE NEW CONCEPTS INCORPORATING ADVANCED TECHNOLOGY

CS-79-1749

LEAN PREMIXED PREVAPORIZED COMBUSTOR

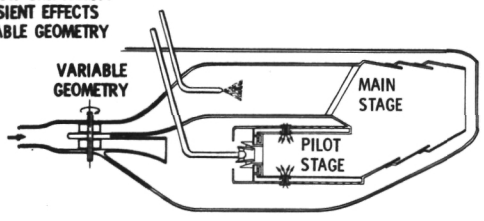
REQUIRED RESEARCH AREAS



LEAN PREMIXED PREVAPORIZED COMBUSTOR

REQUIRED RESEARCH AREAS

AIRFLOW UNIFORMITY
TRANSIENT EFFECTS
VARIABLE GEOMETRY

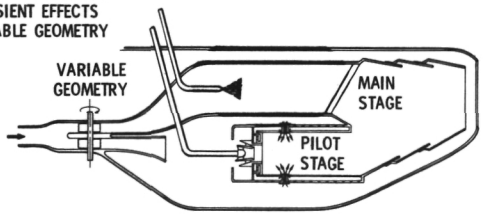


LEAN PREMIXED PREVAPORIZED COMBUSTOR

REQUIRED RESEARCH AREAS

FUEL DISTRIBUTION
FUEL VAPORIZATION
AUTOIGNITION
FLASHBACK

AIRFLOW UNIFORMITY
TRANSIENT EFFECTS
VARIABLE GEOMETRY



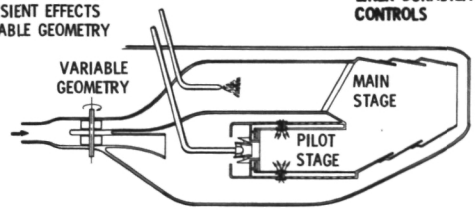
LEAN PREMIXED PREVAPORIZED COMBUSTOR

REQUIRED RESEARCH AREAS

FUEL DISTRIBUTION
FUEL VAPORIZATION
AUTOIGNITION
FLASHBACK

LEAN STABILITY
ALTITUDE RELIGHT
LINER DURABILITY
CONTROLS

AIRFLOW UNIFORMITY
TRANSIENT EFFECTS
VARIABLE GEOMETRY



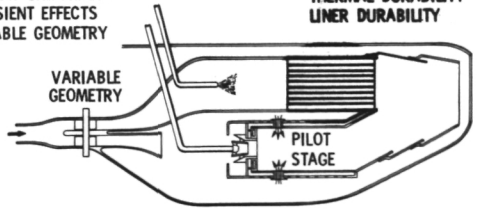
CATALYTIC COMBUSTOR

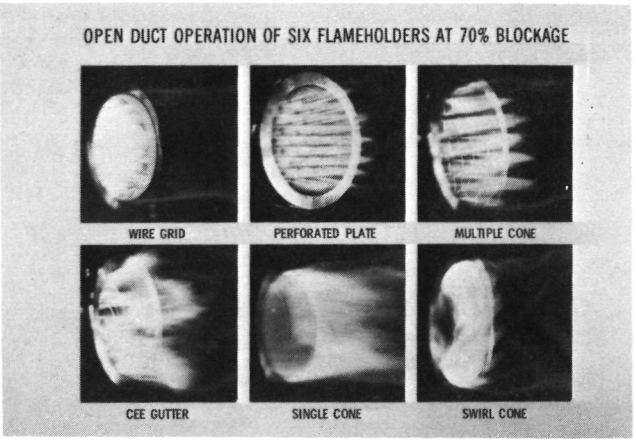
REQUIRED RESEARCH AREAS

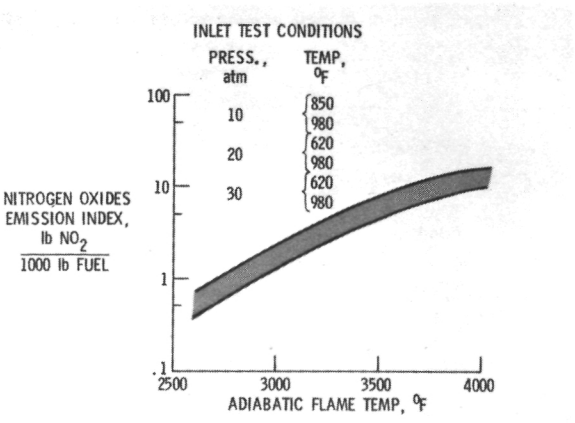
FUEL DISTRIBUTION
FUEL VAPORIZATION
AUTOIGNITION
FLASHBACK

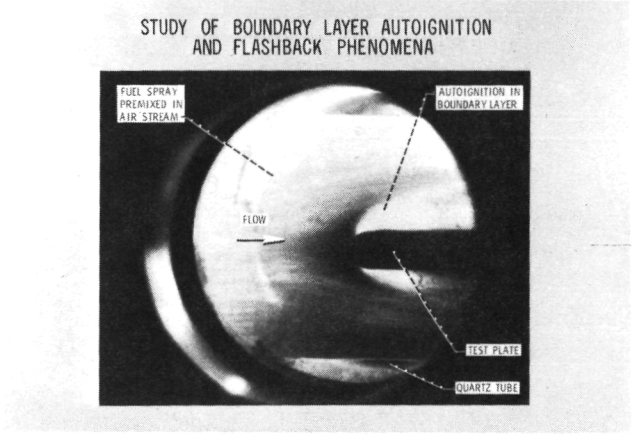
CATALYST ACTIVITY
CATALYST DEGRADATION
THERMAL DURABILITY
LINER DURABILITY

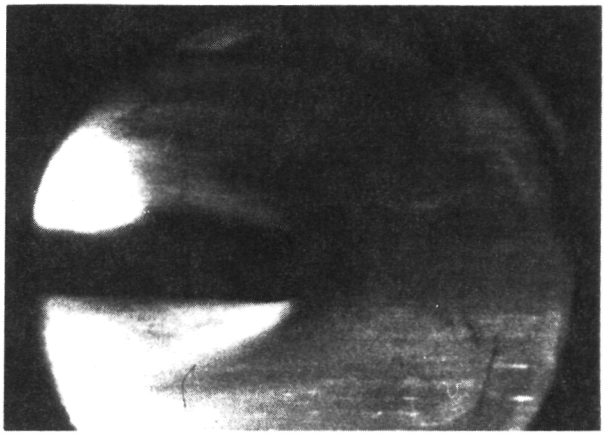
AIRFLOW UNIFORMITY
TRANSIENT EFFECTS
VARIABLE GEOMETRY

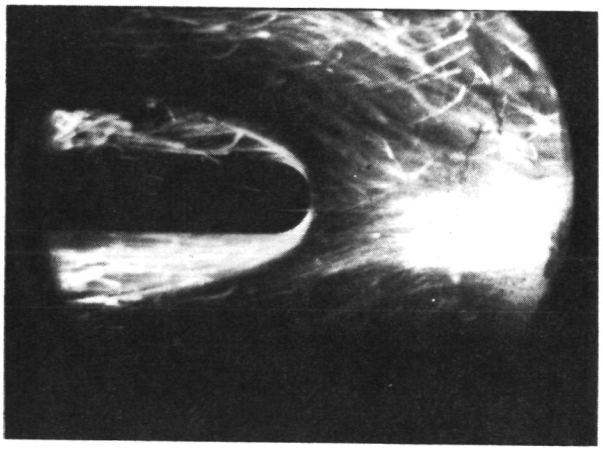


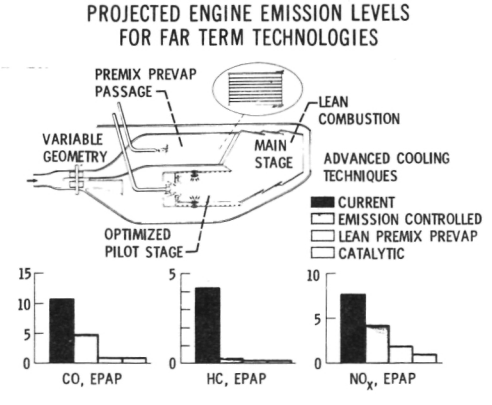

OPEN DUCT OPERATION OF SIX FLAMEHOLDERS AT 70% BLOCKAGE
WIRE GRID
PERFORATED PLATE
MULTIPLE CONE
CEE GUTTER
SINGLE CONE
SWIRL CONE


INLET TEST CONDITIONS
PRESS., atm
TEMP, °F
10
20
30
850
980
620
980
620
980
NITROGEN OXIDES EMISSION INDEX, lb NO2 / 1000 lb FUEL
100
10
1
.1
2500
3000
3500
4000
ADIABATIC FLAME TEMP, °F

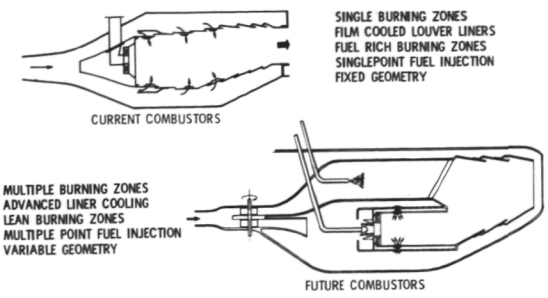

STUDY OF BOUNDARY LAYER AUTOIGNITION AND FLASHBACK PHENOMENA
FUEL SPRAY PREMIXED IN AIR STREAM
AUTOIGNITION IN BOUNDARY LAYER
FLOW
TEST PLATE
QUARTZ TUBE



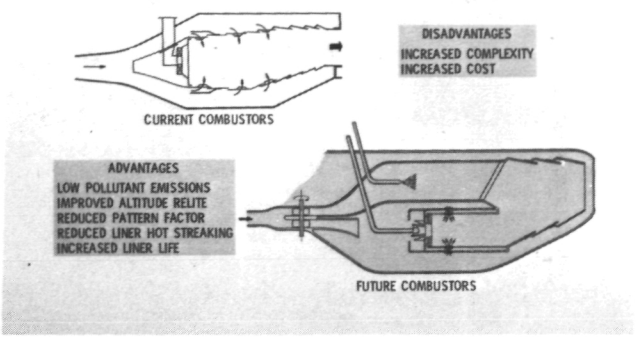



PROJECTED ENGINE EMISSION LEVELS FOR FAR TERM TECHNOLOGIES
PREMIX PREVAP PASSAGE
LEAN COMBUSTION
VARIABLE GEOMETRY
MAIN STAGE
ADVANCED COOLING TECHNIQUES
OPTIMIZED PILOT STAGE
CURRENT
EMISSION CONTROLLED
LEAN PREMIX PREVAP
CATALYTIC
15
10
5
0
CO, EPAP
5
0
HC, EPAP
10
5
0
NOx, EPAP

COMPARISON OF FEATURES



ADVANTAGES - DISADVANTAGES



CONCLUSIONS

NEAR TERM

DRAMATIC REDUCTIONS IN POLLUTANT EMISSIONS ACHIEVED IN COMBUSTION SYSTEMS

DEVELOPMENT INTO FLIGHT SYSTEMS REMAINS

FAR TERM

STUDIES IDENTIFIED MIN. POLLUTANT EMISSION LEVELS

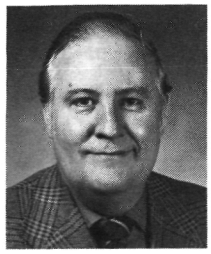
REALIZATION OF POTENTIAL IN COMBUSTION SYSTEMS HAS YET TO BE ESTABLISHED

CS-79-1756

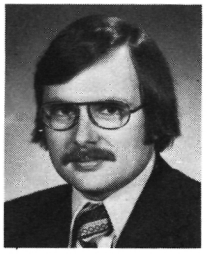
D3

III. NOISE REDUCTION

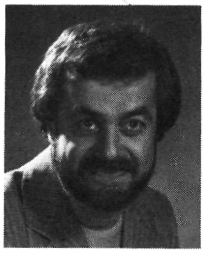
Charles E. Feiler, Chairman
John F. Groeneweg
Francis J. Montegani
John P. Raney
Edward J. Rice
James R. Stone



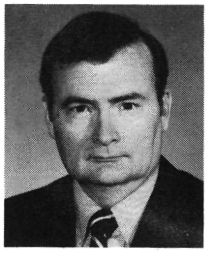
CHARLES E. FEILER is Chief of the Propulsion Systems Acoustics Branch, V/STOL and Noise Division, at NASA Lewis. He joined the Lewis staff in 1951 after receiving a B.S. degree from Georgetown College and M.S. and Ph.D. degrees from Western Reserve University. He has conducted research in rocket combustion kinetics and rocket combustion instability in addition to work on turbomachinery noise and its suppression. In 1975, he was awarded the NASA Exceptional Service Medal.



JOHN F. GROENEWEG was awarded B.S. and Ph.D. degrees in mechanical engineering by the University of Wisconsin. From 1964 to 1967, he worked on rocket combustion problems at NASA Lewis as a member of the U.S. Air Force. Since joining the Lewis staff in 1967, he has worked in research and development areas related to aircraft noise reduction, including acoustic suppressor performance, acoustic technology associated with refanning engines, and fan noise. Currently, he is Head of the Turbomachinery Noise Section, V/STOL and Noise Division.

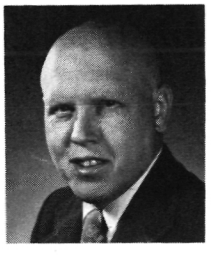


FRANCIS J. MONTEGANI is Head of Section B, Jet Acoustics Branch, V/STOL and Noise Division, at NASA Lewis. A native of Boston, Massachusetts, he received B.S. and M.S. degrees in mechanical engineering from Northeastern University and a Ph.D. degree from Syracuse University. He began his Lewis career in 1967 and later became a member of the Quiet Engine Project Office. He was appointed to his present position in 1975, where he specializes in propulsion system acoustics and aircraft noise reduction.



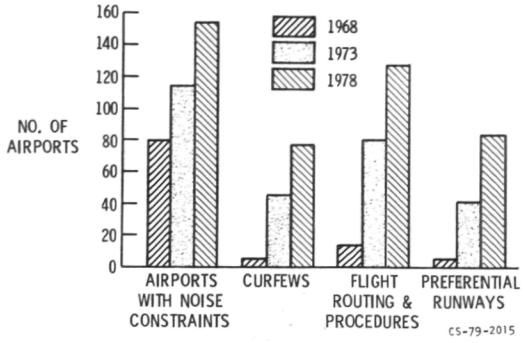
JOHN P. RANEY, after earning a Ph.D. degree from Purdue University in 1959, joined the engineering faculty at the University of Virginia as associate professor of mechanical engineering. In 1963 he accepted a position at NASA Langley, where for 7 years he conducted research on launch vehicle structural dynamics. In 1970, he was appointed to head the NASTRAN Systems Management Office; in 1973, to head the Aircraft Noise Prediction Office; and in 1978, to his present position as Head of the Noise Technology Branch.

EDWARD J. RICE is Head of the Acoustics Section, V/STOL and Noise Division, at NASA Lewis. He obtained a B.S. degree from the University of Wisconsin in 1958 and a Ph.D. degree in mechanical engineering in 1966. While serving in the U.S. Air Force, he worked on rocket combustion problems at Lewis from 1963 to 1965 and then joined the Lewis staff. He is currently involved in acoustic suppression and radiation analysis.

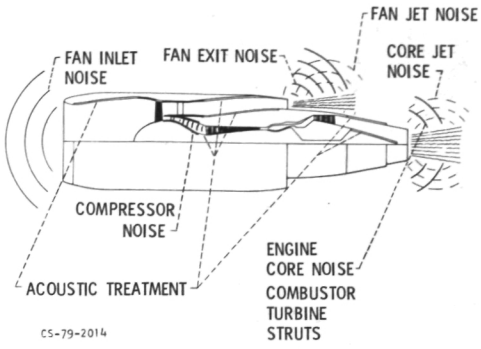


JAMES R. STONE joined NASA Lewis in 1962 after graduating from Case Institute of Technology with a B.S. degree in chemical engineering. In 1967, he received an M.S. degree in chemical engineering, also from Case. Since 1971, he has specialized in aeroacoustics research and the development of semiempirical prediction procedures. He is currently Head of Section A, Jet Acoustics Branch, V/STOL and Noise Division.

NOISE CONSTRAINTS AT MAJOR WORLD AIRPORTS



TURBOFAN ENGINE NOISE SOURCES



NOISE RESEARCH AREAS

FAN NOISE - JOHN GROENWEG
ACOUSTIC SUPPRESSORS - ED RICE
JET NOISE - JIM STONE
CORE ENGINE NOISE - FRANK MONTEGANI
AIRCRAFT NOISE PREDICTION - PHIL RANEY

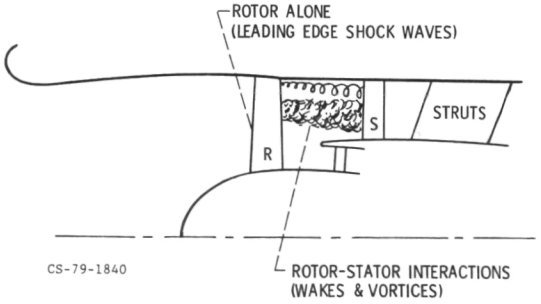
CS-79-2006

NOISE RESEARCH AREAS

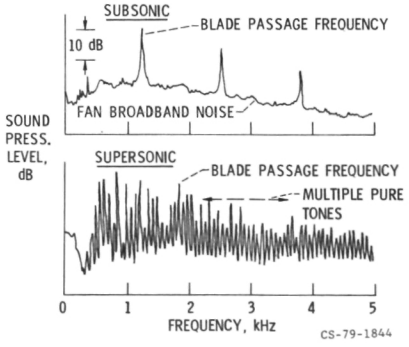
→ FAN NOISE - JOHN GROENWEG
ACOUSTIC SUPPRESSORS - ED RICE
JET NOISE - JIM STONE
CORE ENGINE NOISE - FRANK MONTEGANI
AIRCRAFT NOISE PREDICTION - PHIL RANEY

CS-79-2009

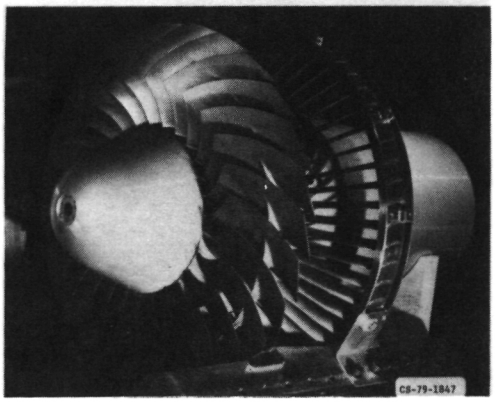
FAN NOISE SOURCES



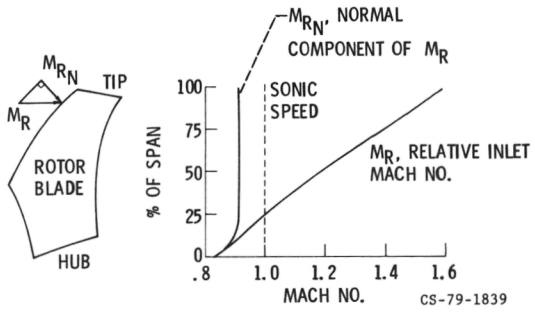
FAN NOISE SPECTRA AT SUBSONIC AND SUPERSONIC TIP SPEEDS



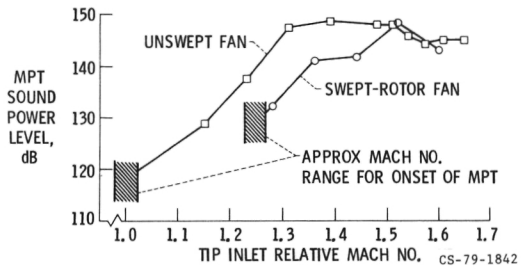
SWEPT-ROTOR FAN



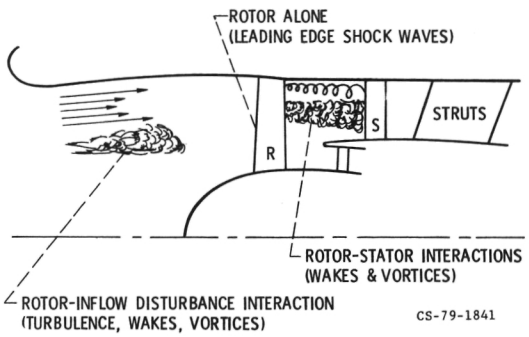
SWEPT ROTOR BLADE



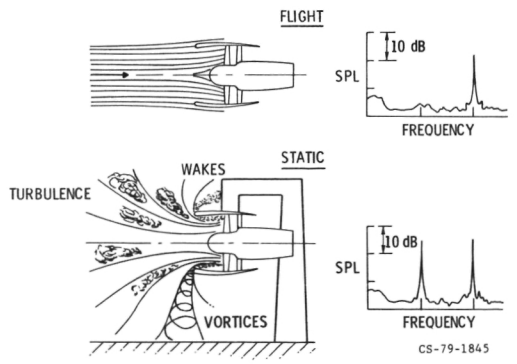
MULTIPLE PURE TONE GENERATION OF UNSWEPT AND SWEPT-ROTOR FANS



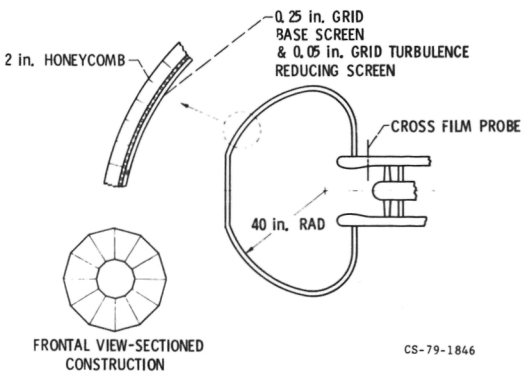
FAN NOISE SOURCES



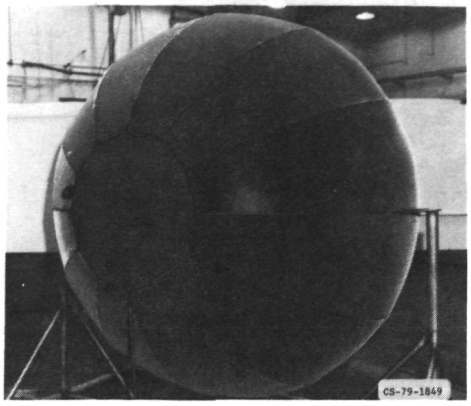
FORWARD VELOCITY EFFECTS ON INLET FLOW AND NOISE



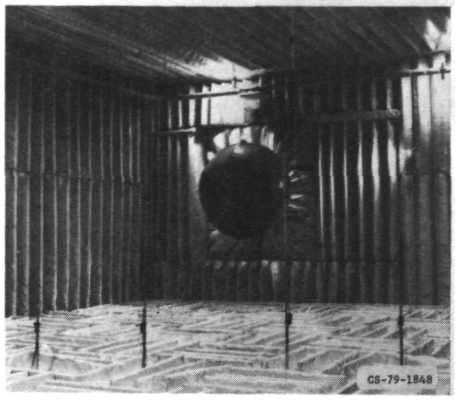
INFLOW CONTROL DEVICE



INFLOW CONTROL DEVICE

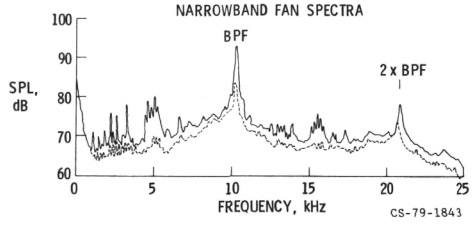


INFLOW CONTROL DEVICE IN ANECHOIC CHAMBER

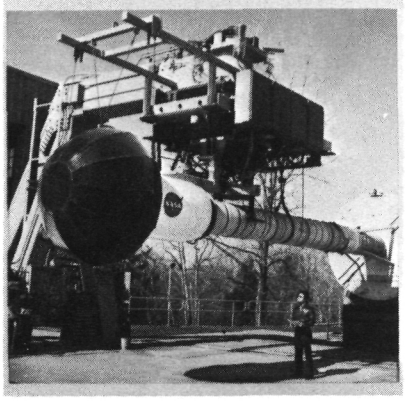


AEROACOUSTIC EFFECTS OF INFLOW CONTROL DEVICE

INLET TURBULENCE		
INFLOW CONTROL DEVICE	TRANSVERSE INTENSITY, %	AXIAL LENGTH SCALE, ft
—— WITHOUT	1.1	18.7
---- WITH	.2	3.3



INFLOW CONTROL DEVICE INSTALLED ON JT15D ENGINE



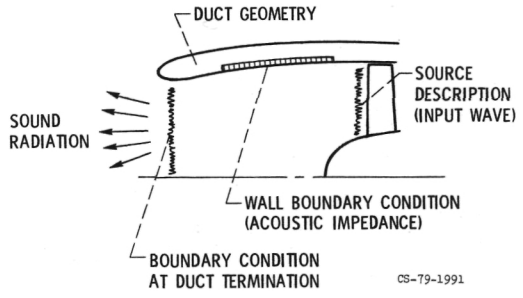
OV-1 AIRCRAFT TO BE USED FOR JT15D FLYOVER NOISE TESTS

NOISE RESEARCH AREAS

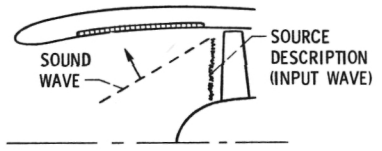
- FAN NOISE - JOHN GROENWEG
- → ACOUSTIC SUPPRESSORS - ED RICE
- JET NOISE - JIM STONE
- CORE ENGINE NOISE - FRANK MONTEGANI
- AIRCRAFT NOISE PREDICTION - PHIL RANEY

CS-79-2010

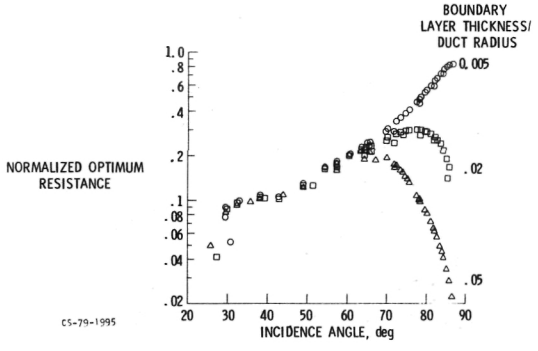
COMPONENTS OF SUPPRESSOR ANALYSIS



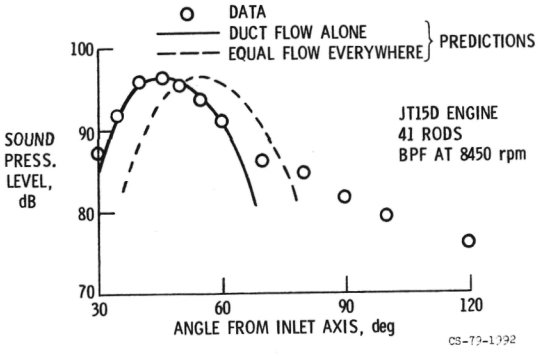
COMPONENTS OF SUPPRESSOR ANALYSIS



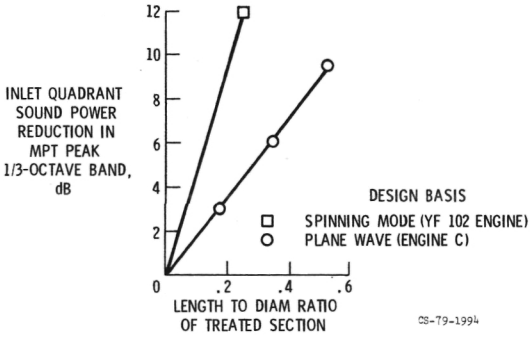
EFFECT OF BOUNDARY LAYER THICKNESS UPON OPTIMUM RESISTANCE-INCIDENCE ANGLE CORRELATION



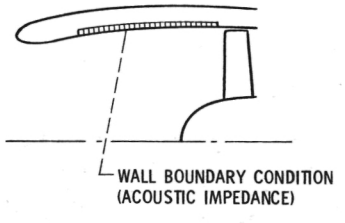
COMPARISON OF MEASURED AND PREDICTED TONE DIRECTIVITIES



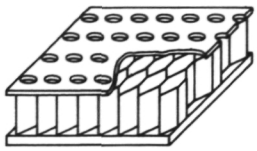
PERFORMANCE OF SUPPRESSORS BASED ON TWO DESIGN METHODS



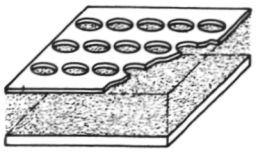
COMPONENTS OF SUPPRESSOR ANALYSIS



LINING MATERIALS AND CONSTRUCTION



PERFORATED PLATE-HONEYCOMB, SINGLE DEG OF FREEDOM (SDOF)

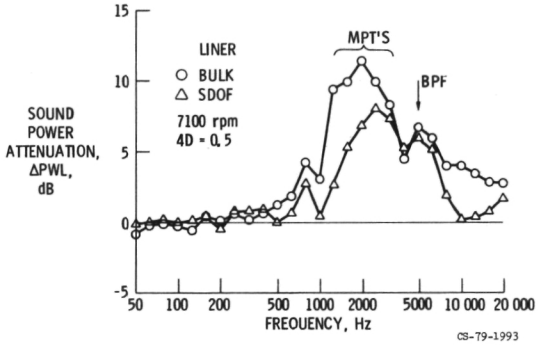


BULK ABSORBER, EXTENDED REACTION

CS-79-1990

AVCO-LYCOMING YF102 ENGINE ON TEST STAND

COMPARISON OF SOUND POWER ATTENUATION SPECTRA FOR BULK AND SDOF LINERS



CS-79-1993

NOISE RESEARCH AREAS

FAN NOISE - JOHN GROENWEG

ACOUSTIC SUPPRESSORS - ED RICE

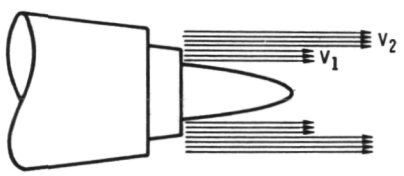
→ JET NOISE - JIM STONE

CORE ENGINE NOISE - FRANK MONTEGANI

AIRCRAFT NOISE PREDICTION - PHIL RANEY

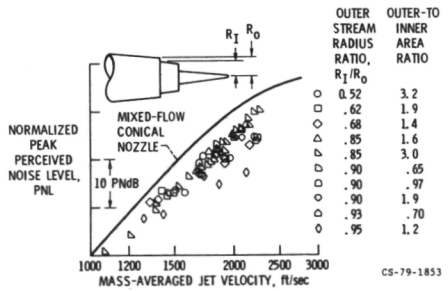
CS-79-2011

INVERTED-VELOCITY-PROFILE COANNULAR JETS



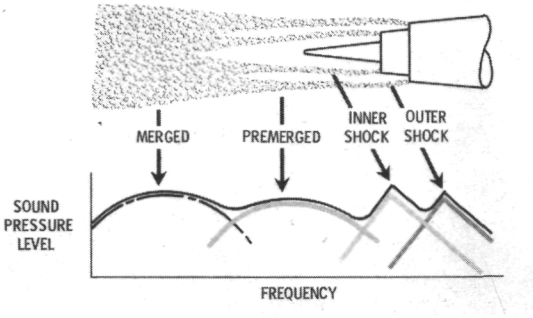
CS-79-1850

NORMALIZED PEAK PNL AS FUNCTION OF MASS-AVERAGED JET VELOCITY

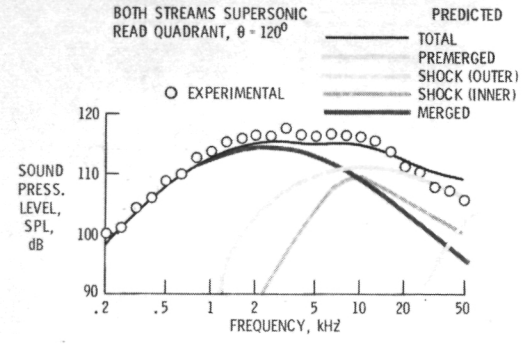


CS-79-1853

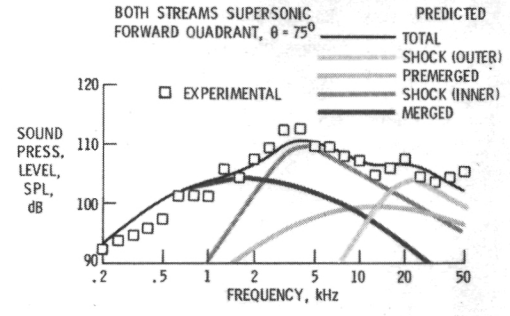
INVERTED-VELOCITY-PROFILE JET NOISE SOURCES



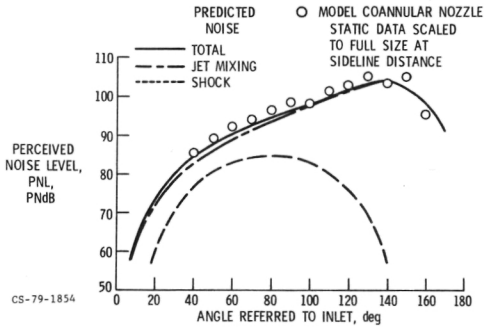
COMPARISON OF INVERTED-VELOCITY-PROFILE JET NOISE PREDICTION WITH STATIC MODEL EXPERIMENTAL DATA



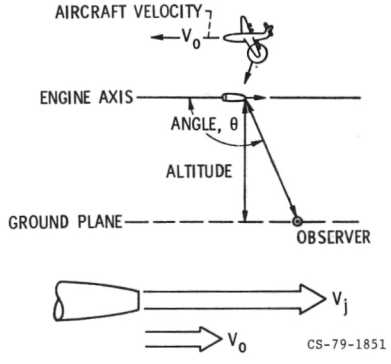
COMPARISON OF INVERTED-VELOCITY-PROFILE JET NOISE PREDICTION WITH STATIC MODEL EXPERIMENTAL DATA



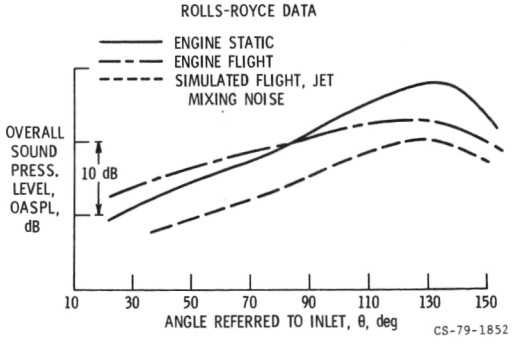
COMPARISON OF EXPERIMENTAL AND PREDICTED PNL DIRECTIVITY



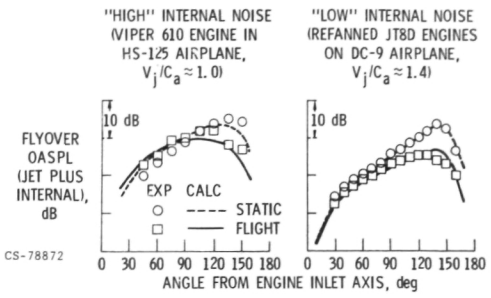
FLIGHT EFFECTS ON EXHAUST NOISE



TYPICAL FLIGHT EFFECTS ON EXHAUST NOISE



STATIC AND FLIGHT DIRECTIVITIES FOR DIFFERENT TYPE ENGINES



NOISE RESEARCH AREAS

FAN NOISE - JOHN GROENWEG

ACOUSTIC SUPPRESSORS - ED RICE

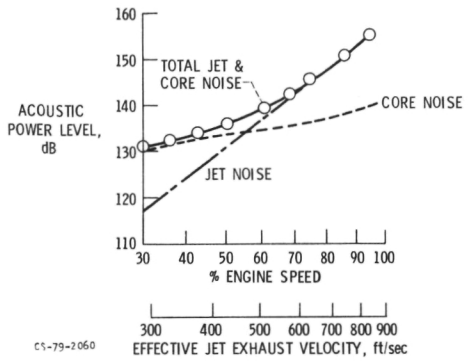
JET NOISE - JIM STONE

→ CORE ENGINE NOISE - FRANK MONTEGANI

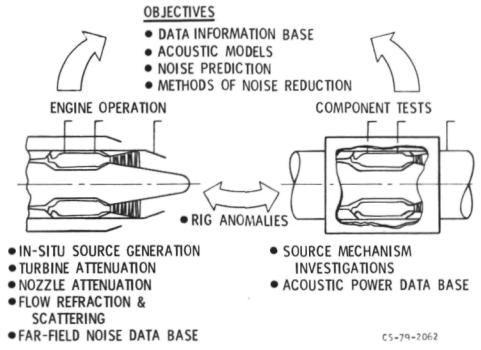
AIRCRAFT NOISE PREDICTION - PHIL RANEY

CS-79-20

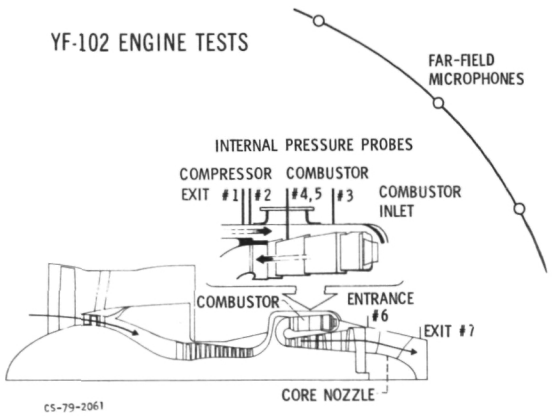
YF-102 ENGINE FAR-FIELD ACOUSTIC POWER



COMBUSTOR NOISE RESEARCH

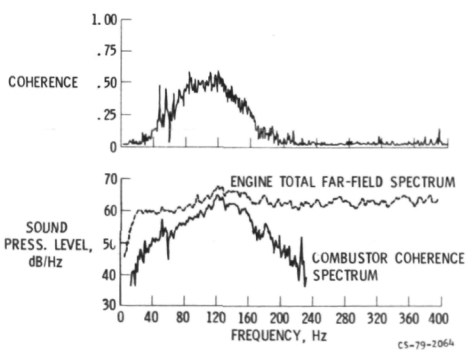


YF-102 ENGINE TESTS

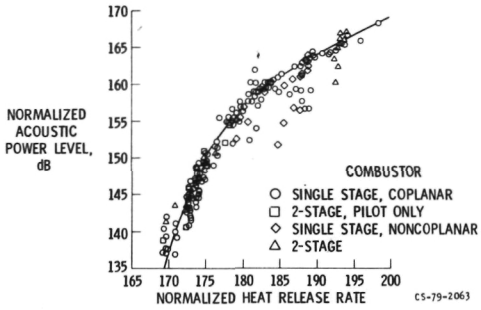


YF-102 COHERENCE AND SOUND PRESSURE LEVEL SPECTRA

FOR 120° & 43% SPEED



CORRELATION OF COMBUSTOR ACOUSTIC POWER LEVELS INFERRED FROM INTERNAL FLUCTUATING PRESSURE MEASUREMENTS



COMBUSTOR NOISE PROGRAM STATUS

CONTINUING ENGINE & RIG EXPERIMENTS

- SIMULTANEOUS INTERNAL/FAR-FIELD MEASUREMENTS (CF6, QCGAT, JT15D)
- COMBUSTOR RIG MODAL PATTERNS & END IMPEDANCE EFFECTS (YF-102)
- DUCT BURNER ENGINE TEST SUPPORT (VCE)

NEW COMPONENT DATA ON SOUND GENERATION & PROPAGATION STIMULATING DEVELOPMENT OF A COMPREHENSIVE ACOUSTIC MODEL

CS-79-2059

NOISE RESEARCH AREAS

FAN NOISE - JOHN GROENWEG

ACOUSTIC SUPPRESSORS - ED RICE

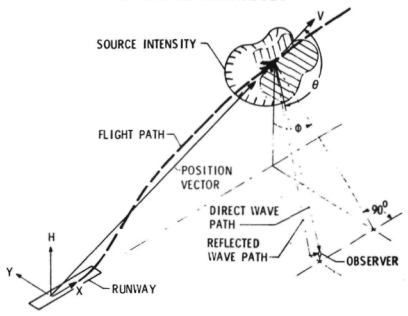
JET NOISE - JIM STONE

CORE ENGINE NOISE - FRANK MONTEGANI

→ AIRCRAFT NOISE PREDICTION - PHIL RANEY

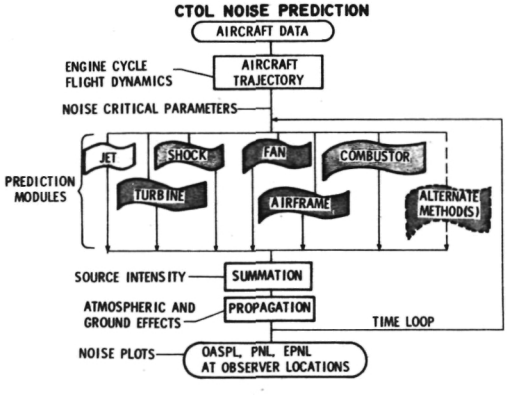
CS-79-2013

PREDICTION METHODOLOGY



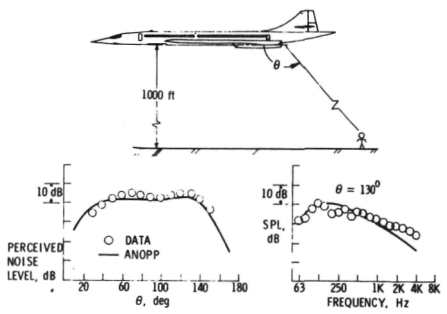
L-5031-1

CTOL NOISE PREDICTION



L-5031-2

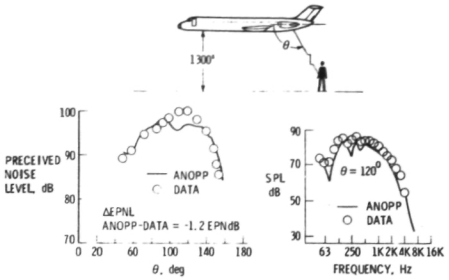
ANOPP FLYOVER NOISE VALIDATION



L-5031-3

ANOPP FLYOVER NOISE VALIDATION

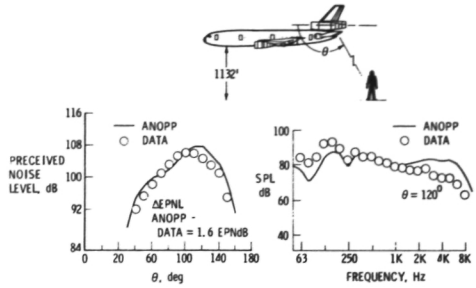
DC-9



L-5031-4

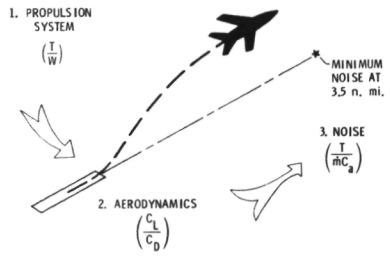
ANOPP FLYOVER NOISE VALIDATION

DC-10



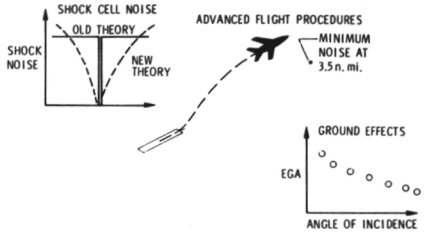
L-5031-5

ANOPP PRELIMINARY DESIGN SYSTEMS STUDIES



L-5031-6

ANOPP RESEARCH IDENTIFICATION



L-5031-7

FUTURE REQUIREMENTS

LaRC/LeRC
ANOPP INTERCENTER DEVELOPMENT

- EXECUTIVE SYSTEM IMPROVEMENTS
- NEW PREDICTION MODULES
- COMPONENT VALIDATION
- SYSTEM VALIDATION

→ NOISE MINIMIZATION PARAMETRIC STUDIES FOR ADVANCED A/C SYSTEM CONCEPTS

L-5031-8

NOISE RESEARCH AREAS

FAN NOISE - JOHN GROENWEG

ACOUSTIC SUPPRESSORS - ED RICE

JET NOISE - JIM STONE

CORE ENGINE NOISE - FRANK MONTEGANI

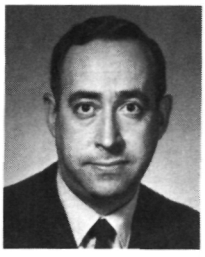
AIRCRAFT NOISE PREDICTION - PHIL RANEY

CS-79-2007

D4

IV. ALTERNATIVE FUELS

Jack Grobman



JACK GROBMAN is Chief of the Fuels Technology Branch, Airbreathing Engines Division, at NASA Lewis, whose staff he joined in 1954 after receiving a B.S. degree in chemical engineering from Case Institute of Technology. He earned an M.S. degree in chemical engineering from Case in 1958. At Lewis he has specialized in gas turbine combustion and fuels research and is currently responsible for research into and technological development of broad-specification hydrocarbon fuels for use in gas turbine engines.

ALTERNATIVE JET AIRCRAFT FUELS

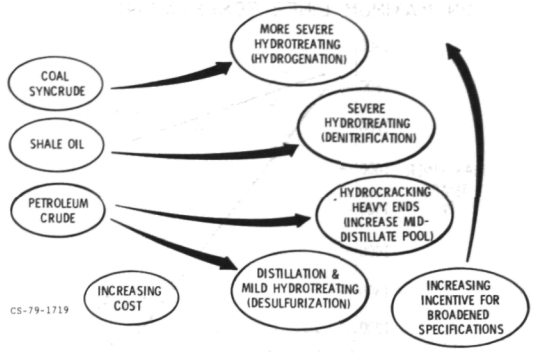
→ POTENTIAL CHANGES IN FUEL PROPERTIES

EFFECTS ON AIRCRAFT ENGINES & FUEL SYSTEMS
- COMBUSTION CHARACTERISTICS
- FUEL THERMAL STABILITY
- FUEL PUMPABILITY

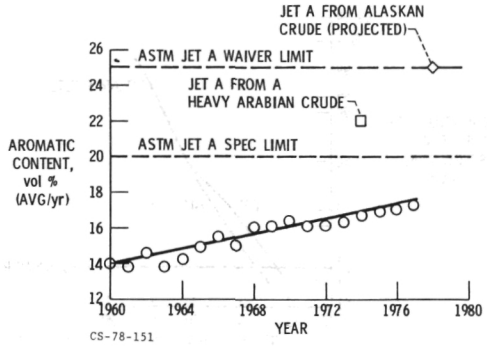
TECHNOLOGY NEEDS
- COMBUSTORS
- FUEL SYSTEMS

CS-79-1560

JET FUEL PRODUCTION ALTERNATIVES



TRENDS IN AROMATIC CONTENT OF COMMERCIAL JET A FUEL



POTENTIAL CHANGES IN FUEL PROPERTIES

PROPERTY	CURRENT JET A	POTENTIAL BROAD-SPEC FUEL
AROMATICS, vol %	17 → 25	30 → 35
HYDROGEN, wt %	14 → 13.5	13.0 → 12.5
FINAL BOILING POINT, °F	500 → 530	550 → 630
FREEZING POINT, °F	-50 → -40	-30 → -20
THERMAL STABILITY	ACCEPTABLE	MARGINAL

CS-79-1558

ALTERNATIVE JET AIRCRAFT FUELS

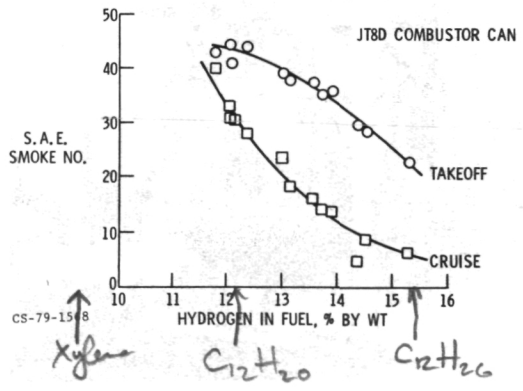
POTENTIAL CHANGES IN FUEL PROPERTIES

→ EFFECTS ON AIRCRAFT ENGINES & FUEL SYSTEMS
- COMBUSTION CHARACTERISTICS
- FUEL THERMAL STABILITY
- FUEL PUMPABILITY

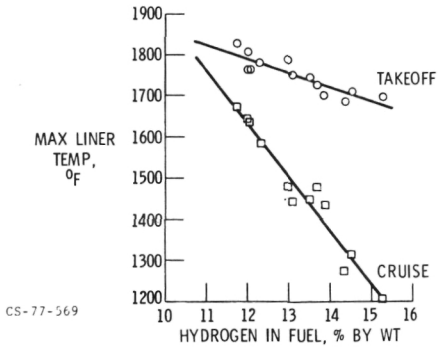
TECHNOLOGY NEEDS
- COMBUSTORS
- FUEL SYSTEMS

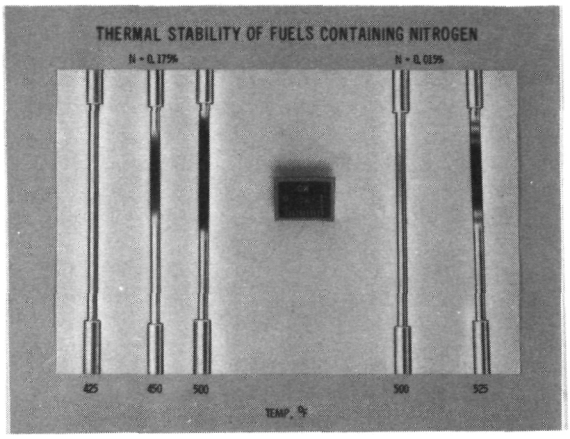
CS-79-1564

EFFECT OF HYDROGEN CONTENT OF FUEL ON SAE SMOKE NUMBER

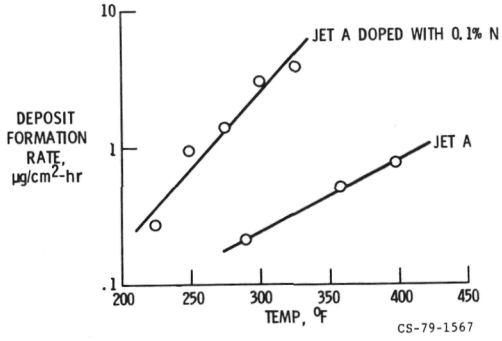


EFFECT OF HYDROGEN CONTENT OF FUEL
ON MAXIMUM LINER TEMPERATURES

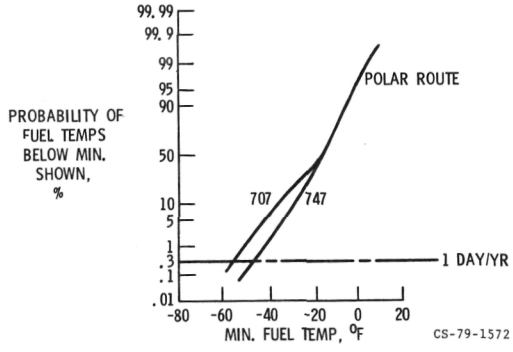




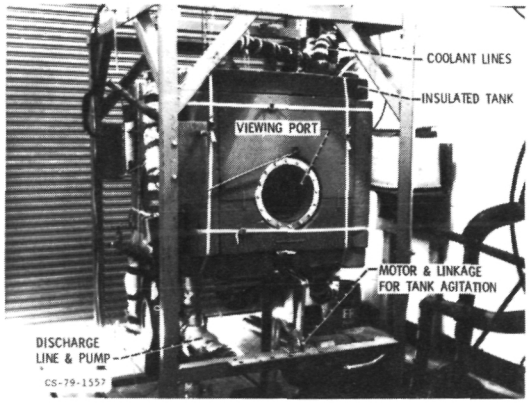
EFFECT OF FUEL NITROGEN CONTENT
ON THERMAL STABILITY

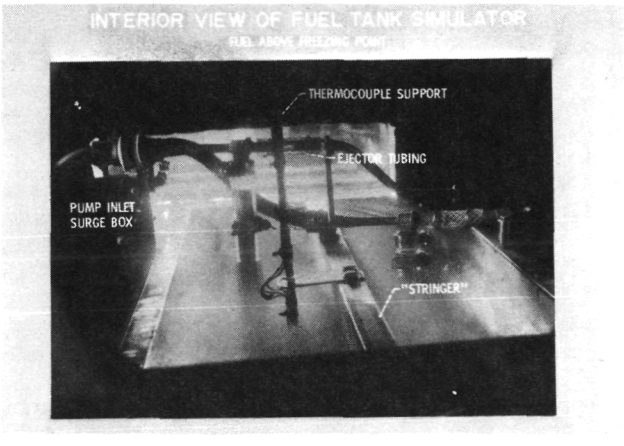


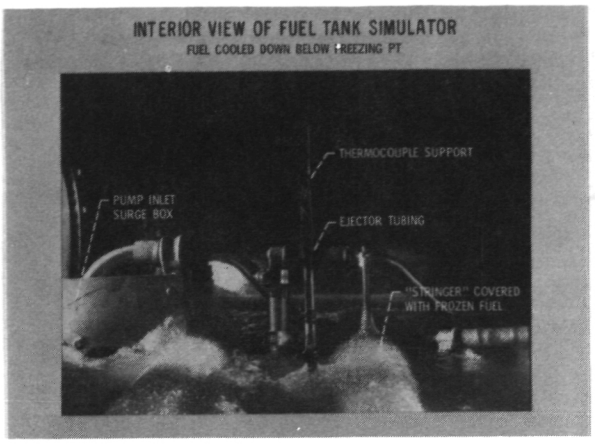
SUMMARY OF IN-FLIGHT MINIMUM FUEL TEMPERATURES



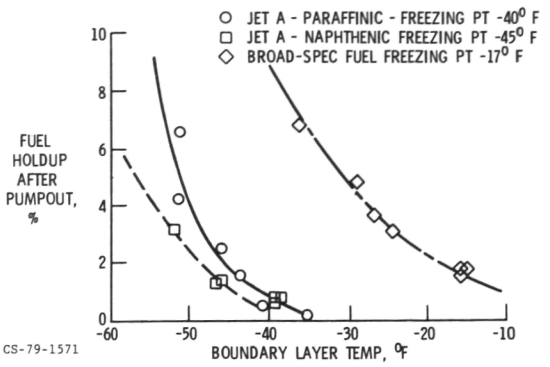
LOW TEMPERATURE FUEL TANK SIMULATOR







LOW TEMPERATURE FUEL TANK BEHAVIOR



CS-79-1571

ALTERNATIVE JET AIRCRAFT FUELS

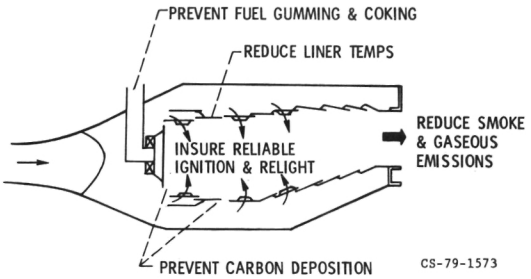
POTENTIAL CHANGES IN FUEL PROPERTIES

EFFECTS ON AIRCRAFT ENGINES & FUEL SYSTEMS
- COMBUSTION CHARACTERISTICS
- FUEL THERMAL STABILITY
- FUEL PUMPABILITY

→ TECHNOLOGY NEEDS
- COMBUSTORS
- FUEL SYSTEMS

CS-79-1563

COMBUSTOR TECHNOLOGY REQUIRED TO USE BROAD-SPEC FUELS



CS-79-1573

CONCEPTUAL APPROACHES TO PERMIT USE OF BROAD-SPEC FUELS

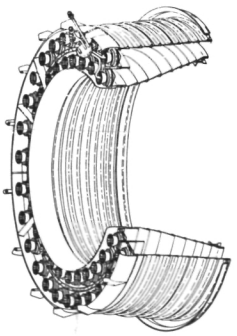
ADVANCED LINERS
- ADVANCED ALLOYS
- IMPROVED CONSTRUCTION
- IMPROVED COOLING EFFECTIVENESS
- CERAMIC COATINGS

LEAN BURNING
- MULTIZONE COMBUSTION
- VARIABLE GEOMETRY
- IMPROVED FUEL-AIR MIXING IN REACTION ZONE

IMPROVED FUEL ATOMIZATION
- AIR ATOMIZATION
- HYBRID DESIGNS
- OPTIMIZED AIR SWIRLER/FUEL INJECTOR INTEGRATION

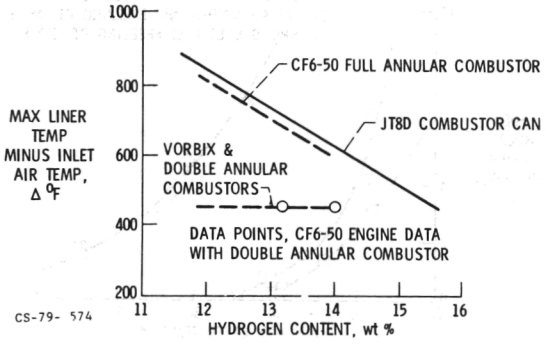
CS-79-1561

DOUBLE ANNULAR COMBUSTOR

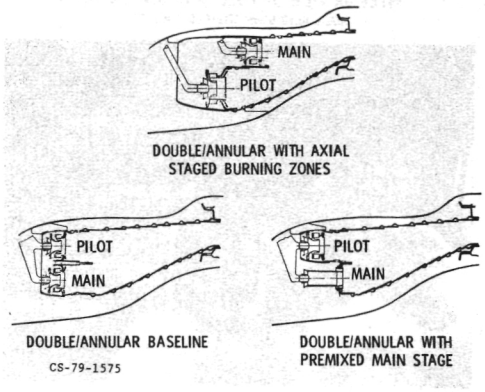


CS-79-1566

EFFECT OF HYDROGEN CONTENT OF FUEL ON LINER TEMPERATURE FOR DIFFERENT COMBUSTORS



COMBUSTOR DESIGN CONCEPTS FOR BROAD-SPEC FUELS



APPROACHES TO PREVENT FUEL SYSTEM FOULING

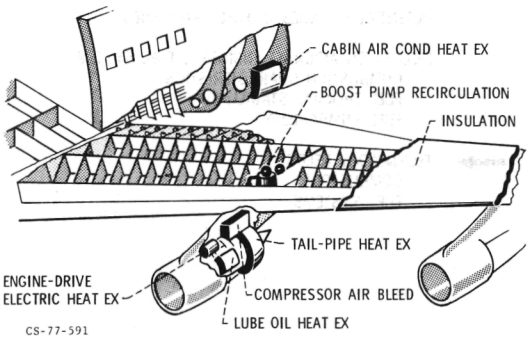
LIMIT MAX FUEL TEMP
- IMPROVED INSULATION OF FUEL MANIFOLD EXPOSED TO HIGH TEMP
- MINIMIZE SURFACE EXPOSURE
- MINIMIZE FUEL RESIDENCE TIME IN MANIFOLD

CONTROL REACTIVE CONSTITUENTS IN FUEL
- OXYGEN REMOVAL
- ANTIOXIDANT ADDITIVES
- REMOVE REACTIVE OR CATALYTIC IMPURITIES
- MINIMIZE SOURCES OF CONTAMINATION DURING DISTRIBUTION

PROVIDE FOR FUEL SYSTEM PURGING

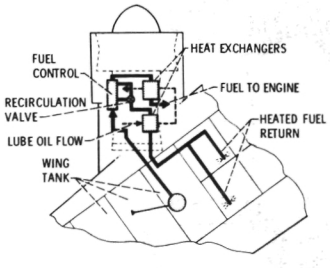
CS-79-1562

FUEL TANK HEATING SOURCES



FUEL HEATING SYSTEM STUDY - BOEING

FUEL/OIL HEAT EXCHANGER SYSTEM



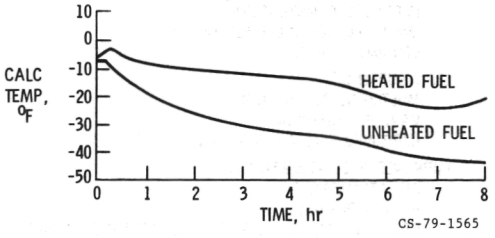
ADVANTAGES
- USES EXISTING HEAT REJECTION HARDWARE
- LOW COST - LOW PENALTY
- SIMPLE SYSTEM, RELATIVELY MINOR MODIFICATION

DISADVANTAGES
- LIMITATION TO QUANTITY OF HEAT AVAILABLE (-30° F FREEZE PT MAX.)
- VARIABLE HEAT AVAILABLE, DEPENDENT ON ENGINE OPERATING POINT

CD-12314-07
CS-78-2880

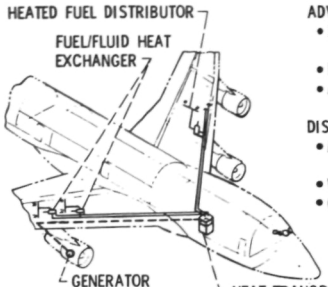
PERFORMANCE OF LUBE-OIL HEATER FOR IN-FLIGHT FUEL HEATING

2800 Btu/min AVG RATE



CS-79-1565

ELECTRICAL FUEL HEATING CONCEPT - BOEING



ADVANTAGES
- HEAT AVAIL FOR FUEL WITH 0^{0} F FREEZE PT
- INDEPENDENT CONTROL
- ADAPTABLE TO GROUND HEATING FOR LAYOVER

DISADVANTAGES
- MAJOR MODIFICATION-ADDITIONAL SYSTEM
- WEIGHT PENALTY
- CYCLE PENALTY WHEN USED

CS-79-1569

CONCLUDING REMARKS

SHIFTS IN SUPPLY & QUALITY OF REFINERY FEED STOCKS WARRANT THE CONSIDERATION OF BROADENING JET AIRCRAFT FUEL SPECS

ADVANCED COMBUSTOR & FUEL SYSTEM TECHNOLOGY WILL BE REQUIRED TO COUNTERACT ADVERSE FUEL PROPERTY EFFECTS

A SOUND & COMPLETE DATA BASE MUST BE DEVELOPED AS SOON AS POSSIBLE IN ORDER TO ESTABLISH ACCEPTABLE SPECS FOR FUTURE JET AIRCRAFT FUELS

CS-79-1570

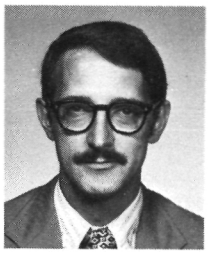
D5

V. MATERIALS AND STRUCTURES TECHNOLOGY

Robert A. Signorelli, Chairman
Thomas K. Glasgow
Gary R. Halford
Stanley R. Levine

ROBERT A. SIGNORELLI is Head of the Metal Matrix Composite Section, Materials and Structures Division, at NASA Lewis. During his more than 26 years in aircraft gas turbine materials research, he has authored more than 50 papers, has obtained several patents, and has achieved two IR 100 awards. He obtained a B.S. degree in metallurgical engineering from Columbia University and is a member of the AIAA Materials Committee as well as the AIME, ASM, and ASTM.

THOMAS K. GLASGOW, who joined the NASA Lewis staff in 1968, was awarded B.S. and M.S. degrees by Case Institute of Technology. As a member of the Alloys Section, Materials and Structures Division, he specializes in oxide dispersion strengthening. He is Chairman of the Powder Metallurgy Committee of the Metallurgical Society of the AIME.



GARY R. HALFORD began his Lewis career in 1966 after earning B.S., M.S., and Ph.D. degrees in theoretical and applied mechanics from the University of Illinois. He has been actively involved in research on the cyclic flow and fracture of materials since 1959. As a member of the Fatigue Research Section, Materials and Structures Division, he has specialized in developing high-temperature, creep-fatigue life prediction approaches for design use.

STANLEY R. LEVINE is Head of the Coatings Section, Materials and Structures Division, at NASA Lewis. After obtaining a B.S. degree in chemical engineering from the City College of New York in 1964 and M.S. and Ph.D. degrees from the City University of New York in 1966 and 1969, respectively, he joined the U.S. Army Propulsion Laboratory at Lewis in 1969. He has specialized in high-temperature surface protection for gas turbines and reentry vehicles.

MAJOR THRUSTS OF MATERIALS AND STRUCTURES RESEARCH FOR PROPULSION SYSTEMS

UNDERSTAND MATERIALS & STRUCTURES PERFORMANCE LIMITATIONS

IMPROVE MATERIALS

USE MATERIALS & STRUCTURAL CONCEPTS MORE EFFECTIVELY

CS-79-1513

MATERIALS AND STRUCTURES PRESENTATION ROAD MAP

HOT SECTION COMPONENTS - BLADES, VANES, COMBUSTORS
- MATERIAL REQUIREMENTS
- IMPROVED MATERIALS
- IMPROVED ENVIRONMENTAL PROTECTION SYSTEMS
- DEVELOPMENT OF LIFE PREDICTION METHODS

INTERMEDIATE TEMP COMPONENTS - DISKS

COLD SECTION COMPONENTS - FAN BLADES, STATIC STRUCTURE

CS-79-1522

MATERIALS AND STRUCTURES PRESENTATION ROAD MAP

HOT SECTION COMPONENTS - BLADES, VANES, COMBUSTORS
- → MATERIAL REQUIREMENTS
- IMPROVED MATERIALS
- IMPROVED ENVIRONMENTAL PROTECTION SYSTEMS
- DEVELOPMENT OF LIFE PREDICTION METHODS

INTERMEDIATE TEMP COMPONENTS - DISKS

COLD SECTION COMPONENTS - FAN BLADES, STATIC STRUCTURE

CS-79-1523

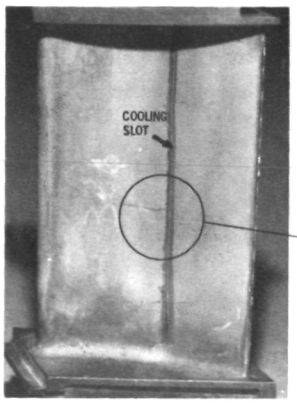
MATERIALS REQUIREMENTS FOR HOT SECTION COMPONENTS

STRENGTH TO PERMIT INCREASED USE TEMP

THERMAL FATIGUE RESISTANCE FOR INCREASED DURABILITY

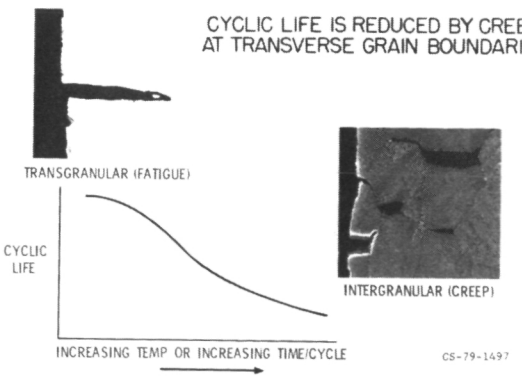
RESISTANCE TO ENVIRONMENTAL ATTACK FOR INCREASED DURABILITY

CS-79-1501



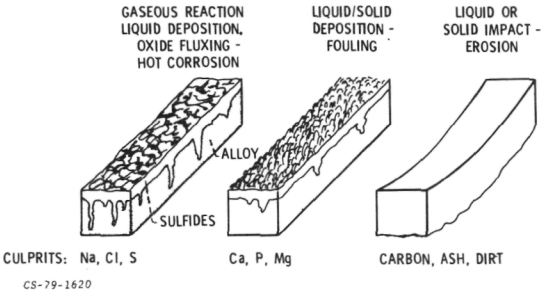
THERMAL FATIGUE CRACKS IN COOLED INLET GUIDE VANE

CYCLIC LIFE IS REDUCED BY CREEP AT TRANSVERSE GRAIN BOUNDARIES



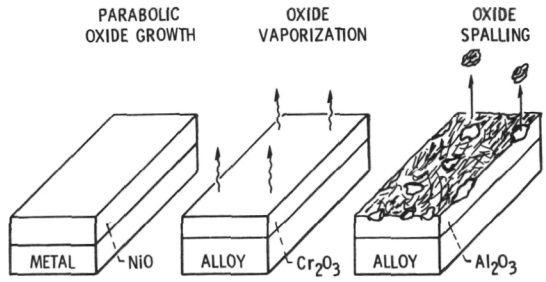
CS-79-1497

SCHEMATIC OF MODES OF HOT CORROSION/EROSION ATTACK



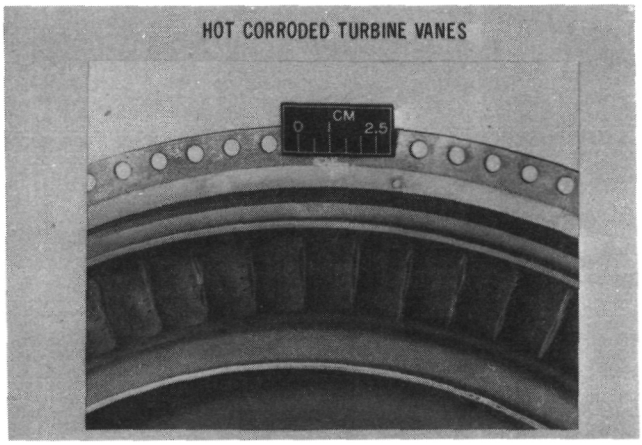
CS-79-1620

SCHEMATIC OF MODES OF OXIDATION ATTACK



CS-79-1618

HOT CORRODED TURBINE VANES



MATERIALS AND STRUCTURES PRESENTATION ROAD MAP

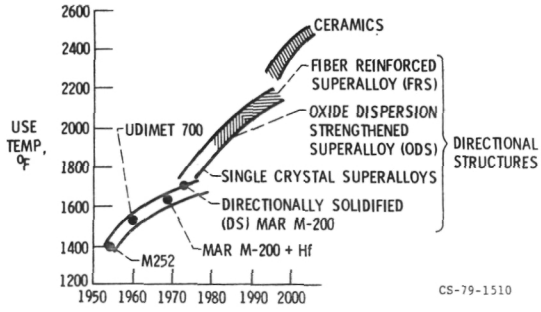
HOT SECTION COMPONENTS - BLADES, VANES, COMBUSTORS
- MATERIAL REQUIREMENTS
- → IMPROVED MATERIALS
- IMPROVED ENVIRONMENTAL PROTECTION SYSTEMS
- DEVELOPMENT OF LIFE PREDICTION METHODS

INTERMEDIATE TEMP COMPONENTS - DISKS

COLD SECTION COMPONENTS - FAN BLADES, STATIC STRUCTURE

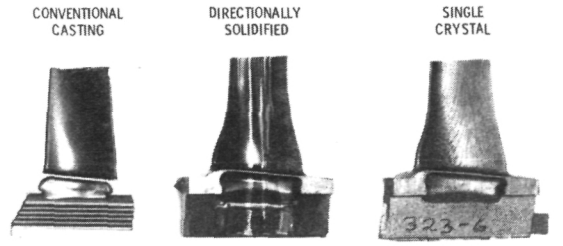
CS-79-1521

PROJECTED USE TEMPERATURES FOR TURBINE BLADE MATERIALS



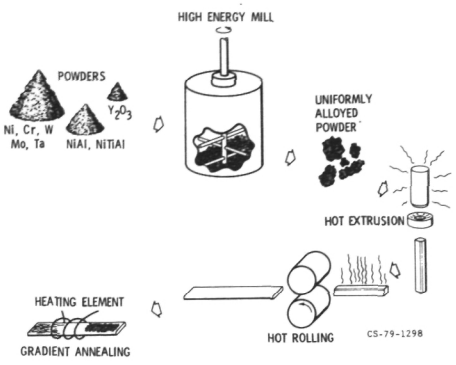
CS-79-1510

CAST TURBINE BLADES

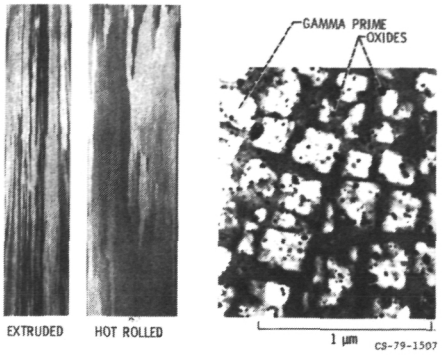


CS-79-1579

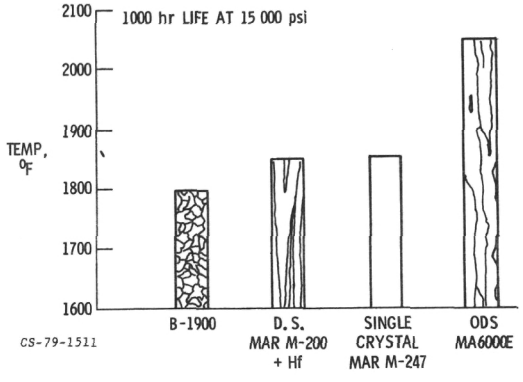
MECHANICAL ALLOYING PROCESS



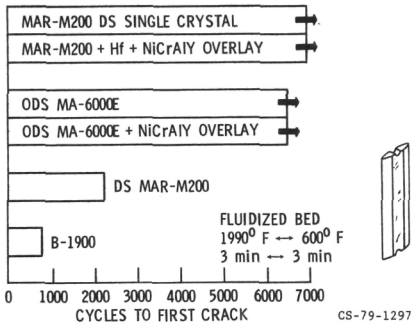
MACRO AND MICROSTRUCTURE OF AN OXIDE DISPERSION STRENGTHENED SUPERALLOY, MA-6000E

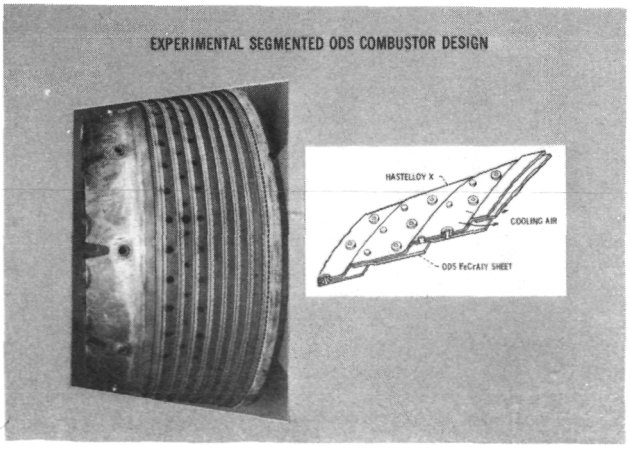


USE TEMPERATURE ADVANTAGE OF ODS SUPERALLOYS

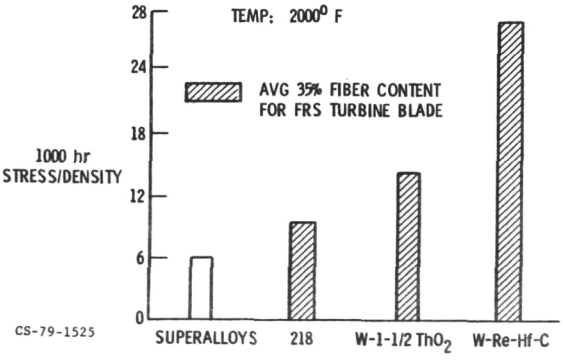


SUPERIOR THERMAL FATIGUE RESISTANCE OF MA-6000E ODS SUPERALLOY



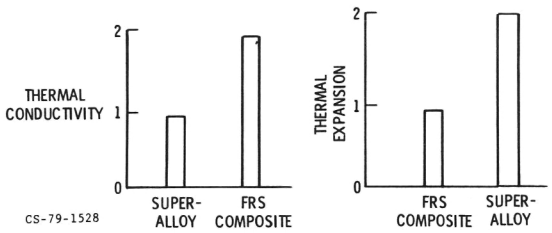


STRENGTH ADVANTAGE OF TUNGSTEN FIBER REINFORCED SUPERALLOY (FRS)



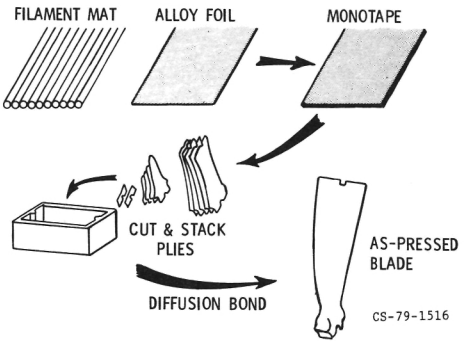
RELATIVE THERMAL CONDUCTIVITY AND THERMAL EXPANSION ADVANTAGE OF FRS OVER SUPERALLOYS

CONDITION: TYPICAL TURBINE BLADE TEMPS



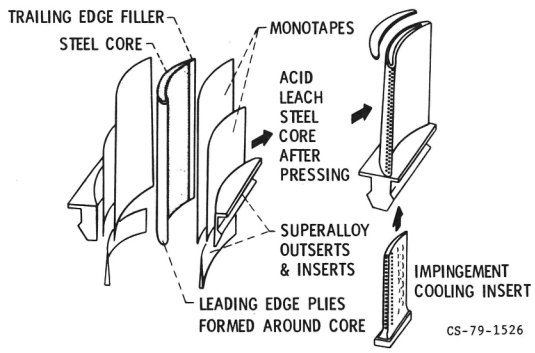
CS-79-1528

FIBER REINFORCED SUPERALLOY FABRICATION PROCESS



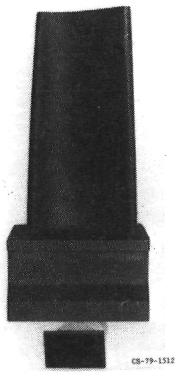
CS-79-1516

COMPOSITE BLADE ASSEMBLY SCHEMATIC



CS-79-1526

COOLED FIBER REINFORCED SUPERALLOY TURBINE BLADE



CS-79-1512

MATERIALS AND STRUCTURES PRESENTATION ROAD MAP

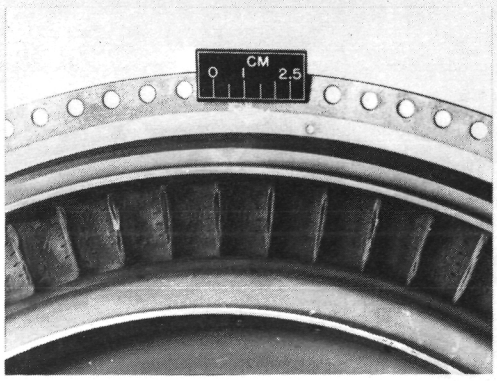
HOT SECTION COMPONENTS - BLADES, VANES, COMBUSTORS
- MATERIAL REQUIREMENTS
- IMPROVED MATERIALS
- → IMPROVED ENVIRONMENTAL PROTECTION SYSTEMS
- DEVELOPMENT OF LIFE PREDICTION METHODS

INTERMEDIATE TEMP COMPONENTS - DISKS

COLD SECTION COMPONENTS - FAN BLADES, STATIC STRUCTURE

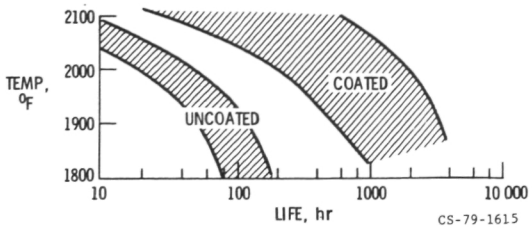
CS-79-1520

HOT CORRODED TURBINE VANES



METALLIC COATINGS EXTEND OXIDATION LIFE OF SUPERALLOYS

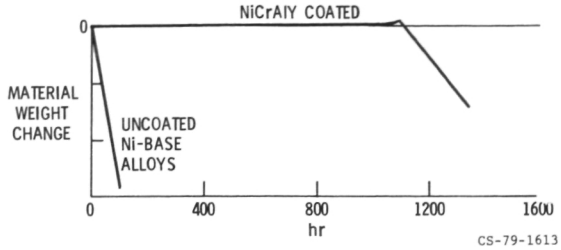
MACH 1 BURNER, 1 hr AT TEMP ⇄ 3 min AT RT



CS-79-1615

METALLIC COATINGS EXTEND HOT CORROSION LIFE OF SUPERALLOYS

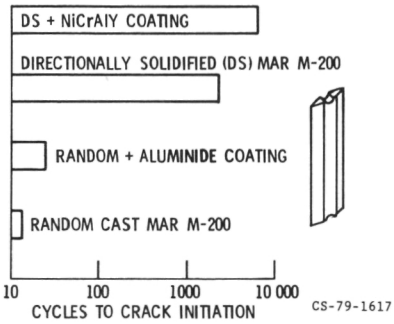
M 0.3 BURNER RIG, 1 hr AT 900° C ⇄ 3 min AT RT; 5 ppm SEA SALT



CS-79-1613

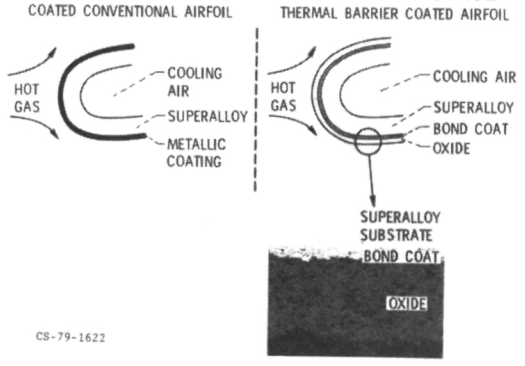
METALLIC COATINGS EXTEND THERMAL FATIGUE LIVES OF SUPERALLOYS

FLUIDIZED BED TEST; 2000° F (3 min) ⇄ 600° F (3 min)



CS-79-1617

SCHEMATIC OF THERMAL BARRIER COATING CONCEPT



CS-79-1622

POTENTIAL BENEFITS OF 10 MIL THERMAL BARRIER COATINGS ON HIGH BYPASS ENGINE

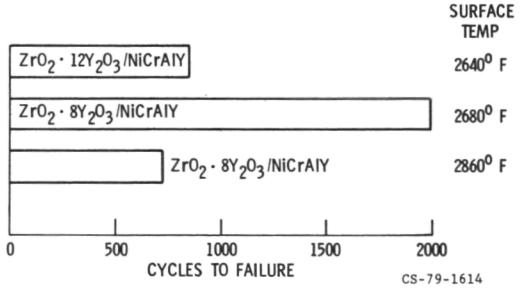
COMPONENT	COOLANT REDUCTION, %	TSFC, %
1ST VANES	4.2 WAE	-0.4
1ST BLADES	1.2	-.4
2ND VANES	.6	-.3
2ND BLADES	.1	-.2
	6.1	-1.3

ALTERNATIVELY, 4X LIFE IMPROVEMENT AT BASELINE COOLANT

CS-79-1612

THERMAL BARRIER COATINGS OFFER LONG LIVES AT VERY HIGH TEMPERATURES

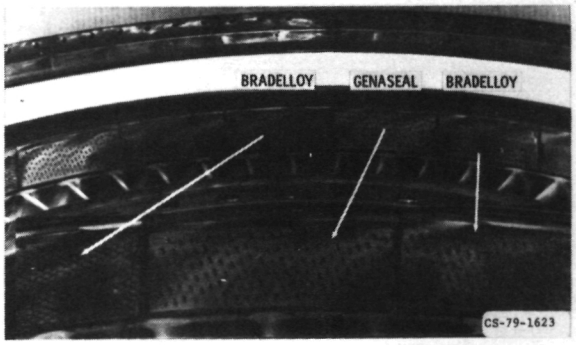
MACH 1 BURNER RIG; 1 hr HOT ⇄ 70° F (30 sec)



CS-79-1614

GENASEAL IS IMPROVED SHROUD MATERIAL

CF6-50C ENGINE GROUND TEST RESULTS



MATERIALS AND STRUCTURES PRESENTATION ROAD MAP

HOT SECTION COMPONENTS - BLADES, VANES, COMBUSTORS
- MATERIAL REQUIREMENTS
- IMPROVED MATERIALS
- IMPROVED ENVIRONMENTAL PROTECTION SYSTEMS
- → DEVELOPMENT OF LIFE PREDICTION METHODS

INTERMEDIATE TEMP COMPONENTS - DISKS

COLD SECTION COMPONENTS - FAN BLADES, STATIC STRUCTURE

CS-79-1519

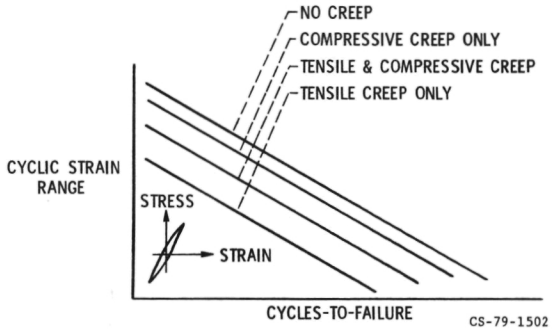
STRAINRANGE PARTITIONING IS METHOD FOR

CHARACTERIZING CREEP-FATIGUE BEHAVIOR OF MATERIALS

PREDICTING THERMAL FATIGUE LIFE OF COMPONENTS

CS-79-1498

CHARACTERIZATION OF CREEP-FATIGUE BEHAVIOR BY STRAINRANGE PARTITIONING



CS-79-1502

CHARACTERIZATION OF ALLOYS BY STRAINRANGE PARTITIONING

6 COUNTRY AGARD/NATO EVALUATION PROGRAM

OVER 50 ENGINEERING ALLOYS

CORRELATES CYCLIC LIVES WITHIN FACTORS OF 2

CS-79-1499

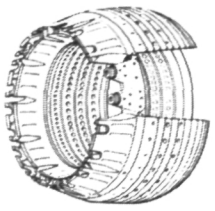
LIFE PREDICTION BY STRAINRANGE PARTITIONING

TURBINE BLADE SQUEALER TIP

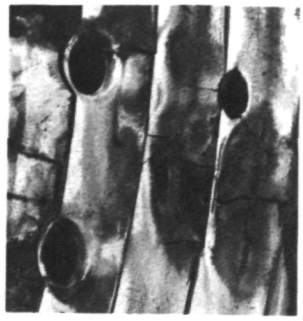
COMBUSTOR LINER

CS-79-1500

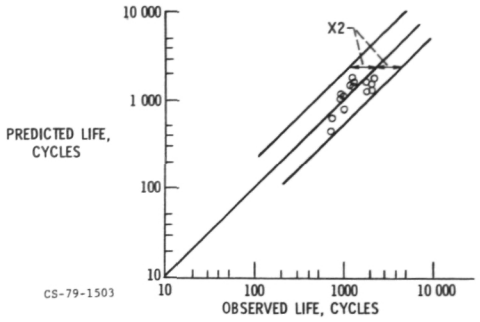
THERMAL FATIGUE CRACKS IN COMBUSTOR LINER



CS-79-1496

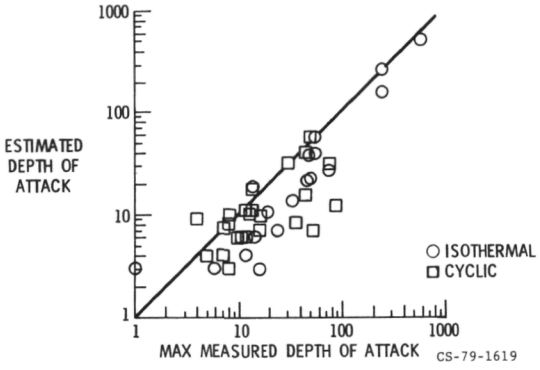


ACCURACY OF STRAINRANGE PARTITIONING IN PREDICTING COMBUSTOR LINER LIFE IN HIGH BYPASS RATIO ENGINES



CS-79-1503

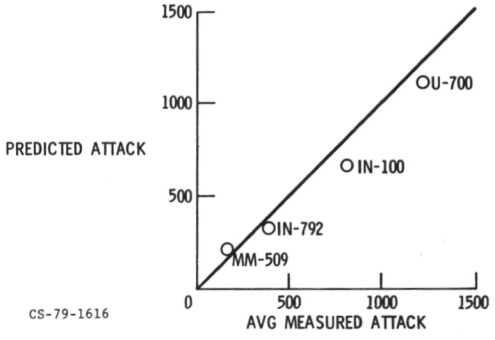
PREDICTION OF OXIDATION ATTACK BY COREST



CS-79-1619

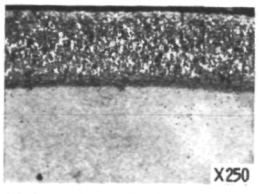
PREDICTION OF HOT CORROSION ATTACK

MACH 0.3 BURNER RIG, 1 hr 1740^{0} F ⇄ 3 min RT, 200 CYCLES
FUEL IMPURITIES IN ppm: 0.9 Na, 0.9 K, 0.45 Ca, 0.45 Mg

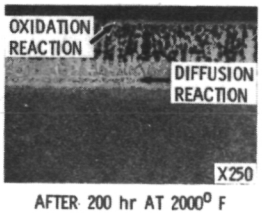


CS-79-1616

ENVIRONMENTAL AND SUBSTRATE REACTIONS DEGRADE COATINGS



AS-DEPOSITED NiCrAlY COATING



AFTER 200 hr AT 2000^{0} F

CS-79-1621

MATERIALS AND STRUCTURES PRESENTATION ROAD MAP

HOT SECTION COMPONENTS - BLADES, VANES, COMBUSTORS
- MATERIAL REQUIREMENTS
- IMPROVED MATERIALS
- IMPROVED ENVIRONMENTAL PROTECTION SYSTEMS
- DEVELOPMENT OF LIFE PREDICTION METHODS

→ INTERMEDIATE TEMP COMPONENTS - DISKS

COLD SECTION COMPONENTS - FAN BLADES, STATIC STRUCTURE

CS-79-1518

DISK REQUIREMENTS

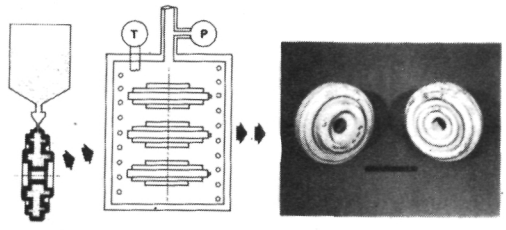
STRENGTH - UNIFORMITY

COST

FATIGUE RESISTANCE

CS-79-1508

HOT ISOSTATIC PRESSING OF LARGE DISK



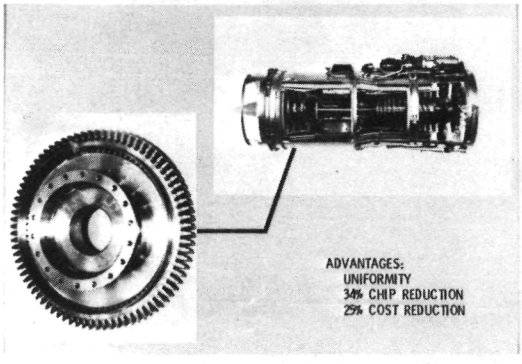
FILLED CONTAINER

HOT ISOSTATIC PRESS

INSPECTION SHAPE

CS-79-1506

FIRST STAGE TURBINE DISK FOR COMMERCIAL ENGINES



ADVANCED DISK ALLOY PROPERTIES

	WROUGHT WASPALOY	WROUGHT ASTROLOY	POWDER METALLURGY IN 100	POWDER METALLURGY NASA II-B7
1200° F UTS, ksi	183	197	196	221
CYCLES TO INITIAL CRACK	8000	24 000	64 000	165 000
CYCLES TO PROPAGATE CRACK TO FAILURE	725	265	75	<10

CS-79-1509

MATERIALS AND STRUCTURES PRESENTATION ROAD MAP

HOT SECTION COMPONENTS - BLADES, VANES, COMBUSTORS
- MATERIAL REQUIREMENTS
- IMPROVED MATERIALS
- IMPROVED ENVIRONMENTAL PROTECTION SYSTEMS
- DEVELOPMENT OF LIFE PREDICTION METHODS

INTERMEDIATE TEMP COMPONENTS - DISKS

→ COLD SECTION COMPONENTS - FAN BLADES, STATIC STRUCTURE

CS-79-1517

APPLICATION OF COMPOSITE MATERIALS TO COLD SECTION COMPONENTS

ROTATING FAN BLADES

STATIC STRUCTURE
- FRAME/CONTAINMENT
- NOZZLE FLAP

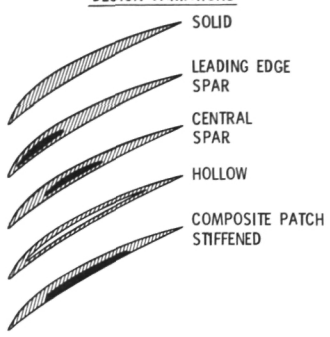
CS-79-1515

BENEFITS OF COMPOSITES FOR COLD SECTION COMPONENTS

- TAILOR PROPERTIES TO COMPONENTS NEED
  - LOWER WEIGHT
  - GREATER STIFFNESS
  - GREATER STRENGTH
- REDUCE COMPONENT WEIGHT
  - BLADES
  - DISK
  - CONTAINMENT
  - INDIRECT
- POTENTIALLY REDUCE COST

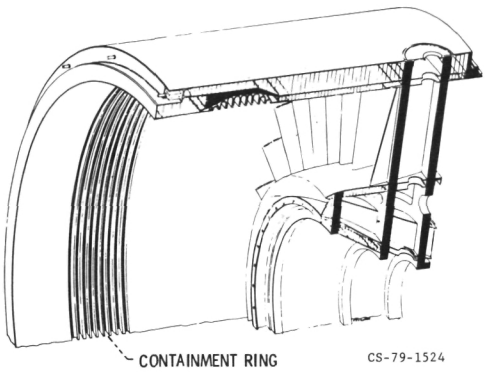
CS-79-1514

COMPOSITE FAN BLADE
MATERIALS & DESIGNS



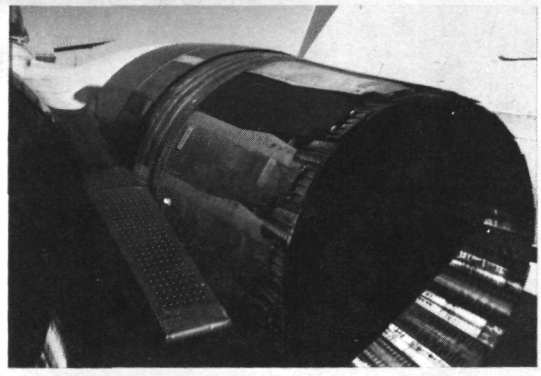
CS-79-1527

COMPOSITE FAN FRAME/CONTAINMENT RING



CS-79-1524

COMPOSITE NOZZLE FLAP FOR F-100 ENGINE



SUMMARY

HOT SECTION
- MAJOR STRIDES MADE IN UNDERSTANDING FAILURE MODES
  - THERMAL FATIGUE
  - OXIDATION/CORROSION
- ACHIEVED IMPROVED MATERIALS & COATING
  - OXIDE DISPERSION STRENGTHENED SUPERALLOYS (~2000^0 F USE TEMP)
  - FIBER REINFORCED SUPERALLOYS (~2100^0 F USE TEMP)
  - METALLIC COATINGS (~2100^0 F)
  - THERMAL BARRIER COATINGS (~2600^0 F)
  - ABRADABLE SEALS (~150^0 F HIGHER USE TEMP)
- DEVELOPING ADVANCED LIFE PREDICTION FOR DESIGN
  - STRAINRANGE PARTITIONING FOR THERMAL FATIGUE
  - COREST FOR OXIDATION ATTACK
  - COATING LIFE ESTIMATION

INTERMEDIATE TEMP SECTION
- POWDER METALLURGY DISKS (~220 ksi UTS)

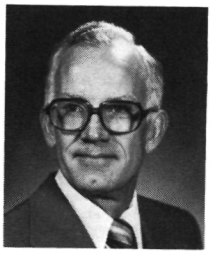
COLD SECTION
- COMPOSITES SHOW PROMISE FOR FAN BLADES, FRAME, NOZZLE FLAPS

CS-79-1529

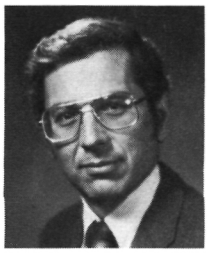
D6

VI. COMPUTATIONAL FLUID MECHANICS OF INTERNAL FLOW

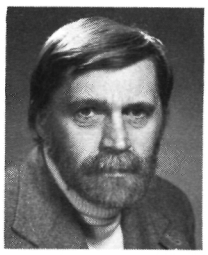
David N. Bowditch, Chairman
John J. Adamczyk
Bernhard H. Anderson
William D. McNally
Peter M. Sockol



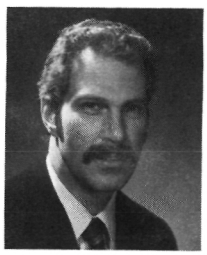
DAVID N. BOWDITCH is Chief of the Propulsion Aerodynamics Branch, Wind Tunnel and Flight Division, at NASA Lewis. A native of the Cleveland, Ohio, area, he joined Lewis in 1955 after obtaining B.S. and M.S. degrees in aeronautical engineering from Purdue University in 1953 and working at Pratt & Whitney Aircraft for 2 years. For the past 13 years, he has supervised work on the design and testing of propulsion system inlets and nozzles and the analysis of their internal flows.



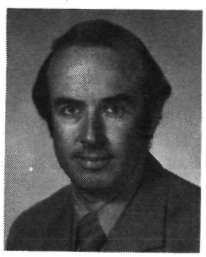
JOHN J. ADAMCZYK joined the NASA Lewis staff in 1975. He received a B.S. degree in mechanical engineering in 1965 and a Ph.D. degree in applied mechanics in 1971, both from the University of Connecticut. As a member of the Computational Fluid Mechanics Branch, Fluid System Components Division, he has specialized in analyzing unsteady flows in turbomachinery and numerically simulating internal transonic flows.



BERNHARD H. ANDERSON is Head of the Aerodynamic Analysis Section, Wind Tunnel and Flight Division, at NASA Lewis. After earning a B.S. degree from Rensselaer Polytechnic Institute and an M.S. degree from Case Western Reserve University, he joined the Lewis staff in 1955. He is specifically concerned with internal computational fluid mechanics for inlets, diffusers, nozzles, and mixers.



WILLIAM D. McNALLY is a member of the Computational Fluid Mechanics Branch, Fluid System Components Division. He began his career at NASA Lewis in 1966 after earning B.S., M.S., and Ph.D. degrees from Carnegie-Mellon University. He has specialized in developing analyses that simulate subsonic and transonic flows through axial- and mixed-flow turbomachinery.



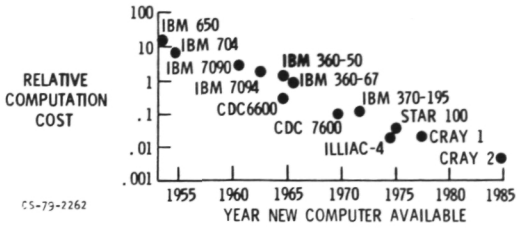
PETER M. SOCKOL came to NASA Lewis in 1962 after receiving B.S. and M.S. degrees from the Carnegie Institute of Technology and MIT, respectively. In 1967, he received an Sc.D. degree in mechanical engineering from MIT. As a member of the Computational Fluid Mechanics Branch, Fluid System Components Division, he is currently investigating methods for analyzing viscous and secondary flows in turbomachinery.

INTERNAL COMPUTATIONAL FLUID MECHANICS FOR PROPULSION SYSTEMS

- SOLUTION TECHNIQUES
- DEVELOPMENT OF A COMPUTER CODE

CS-79-1780

TREND IN COMPUTATION COST



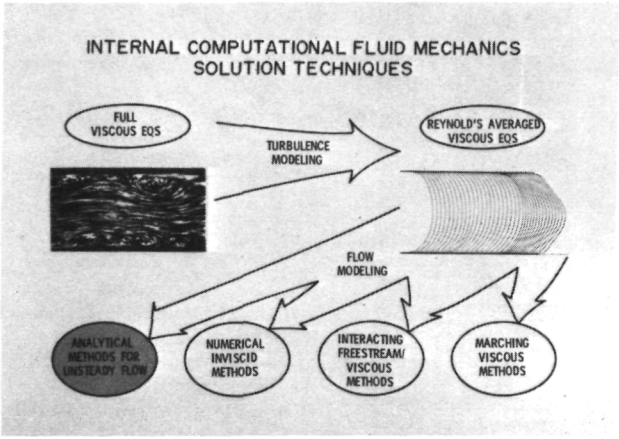
CS-79-2262

GOALS OF INTERNAL COMPUTATIONAL FLUID MECHANICS

GOALS	BENEFITS
RAPID SIMULATION OF COMPLEX FLOW	REDUCED DESIGN COST
DETAILED FLOW FIELD DESCRIPTIONS	REDUCED DESIGN TIME
SIMULATION OF FLOWS THAT ARE EXPERIMENTALLY COSTLY	REDUCED DESIGN RISK
RAPID CONFIGURATION OPTIMIZATION	IMPROVED DESIGN

CS-79-2265

INTERNAL COMPUTATIONAL FLUID MECHANICS SOLUTION TECHNIQUES



ANALYTICAL MODELING FOR UNSTEADY FLOWS

BASED ON

UNSTEADY LINEARIZED AERODYNAMIC THEORY

ASSUMES

DETAILED STEADY STATE FLOW PHYSICS IS NOT GENERALLY REQUIRED

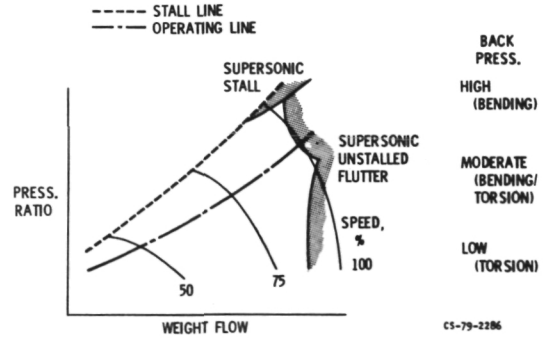
UNSTEADY FLOW FIELD IS VIEWED AS A SMALL PERTURBATION SUPERIMPOSED ON A SIMPLE STEADY FLOW

REQUIRES

RAPID SOLUTIONS THAT ARE COMPUTATIONALLY EFFICIENT

CS-79-2268

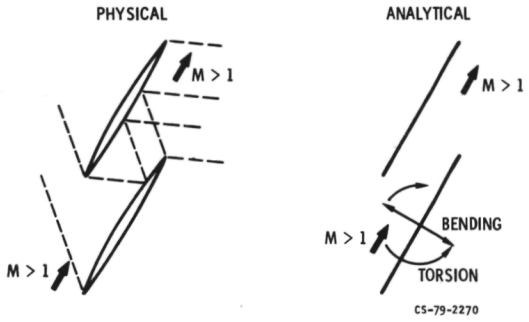
REGIONS OF COMPRESSOR FLUTTER



CS-79-2286

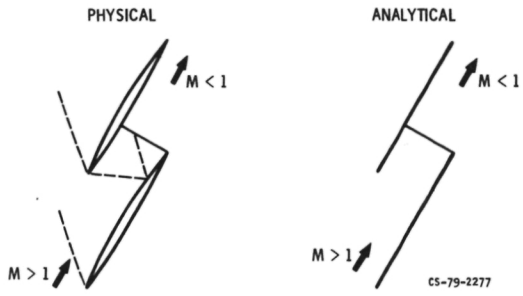
SUPERSONIC UNSTALLED FLUTTER

LOW BACK PRESS. MODEL



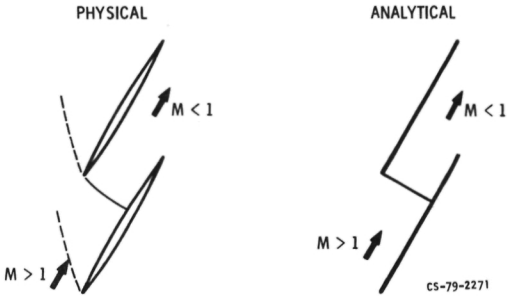
SUPERSONIC UNSTALLED FLUTTER

MODERATE BACK PRESS. MODEL



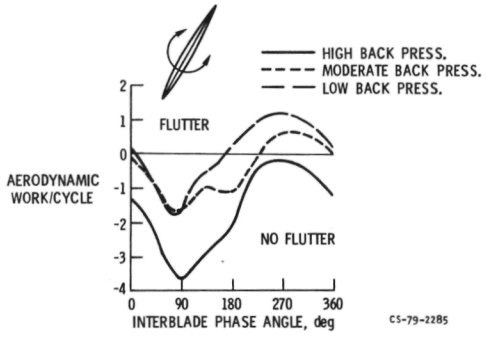
SUPERSONIC UNSTALLED FLUTTER

HIGH BACK PRESS. MODEL



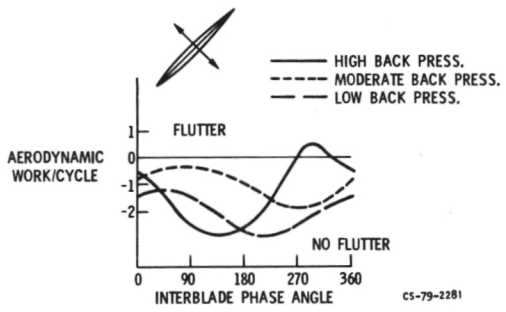
SUPERSONIC UNSTALLED FLUTTER ANALYSES

PREDICTION FOR TORSIONAL MOTION

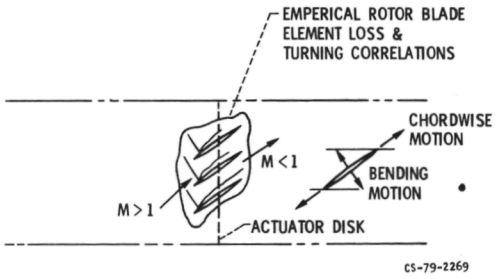


SUPERSONIC UNSTALLED FLUTTER ANALYSES

PREDICTION FOR BENDING MOTION

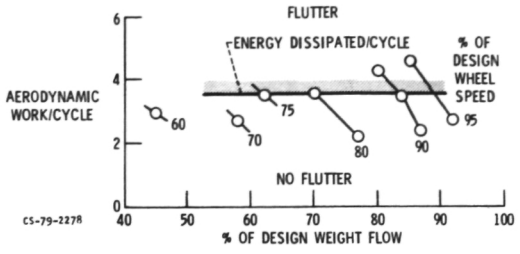


SUPERSONIC STALLED BENDING FLUTTER SEMI EMPIRICAL ANALYSIS



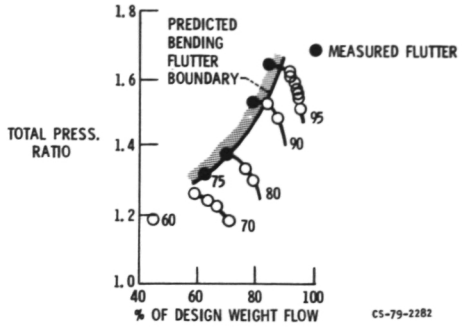
SUPERSONIC STALLED BENDING FLUTTER

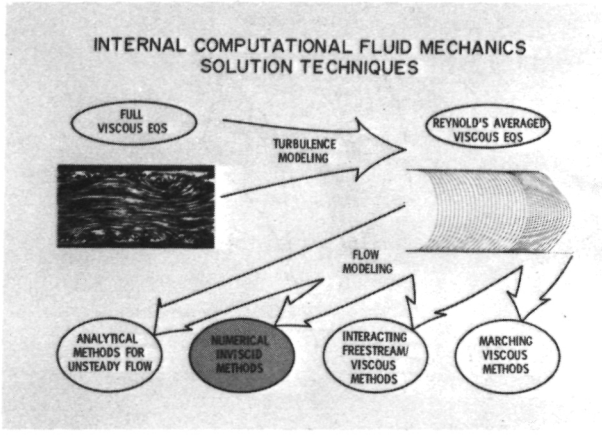
PREDICTION FOR NASA QUIET ENGINE FAN C



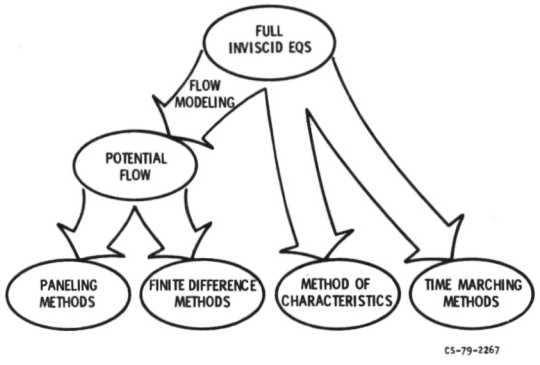
SUPERSONIC STALLED BENDING FLUTTER

COMPARISON OF ANALYSIS & EXPERIMENT; NASA QUIET ENGINE FAN C

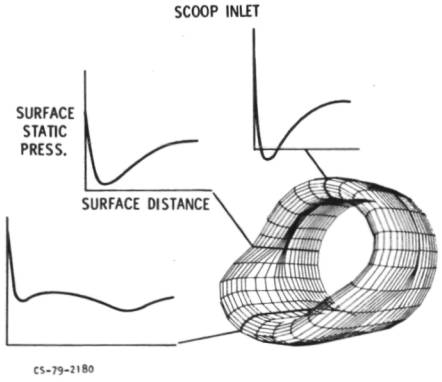




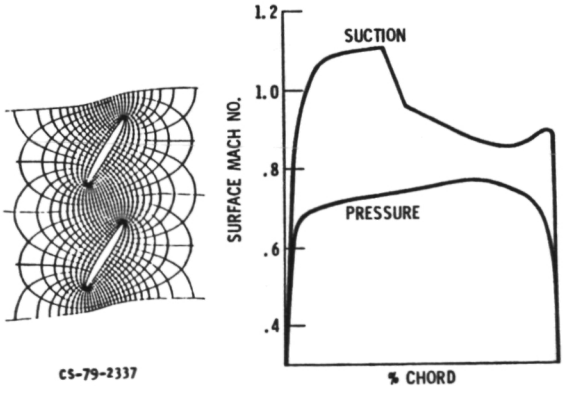
NUMERICAL INVISCID METHODS



3-D POTENTIAL FLOW PANELING METHOD

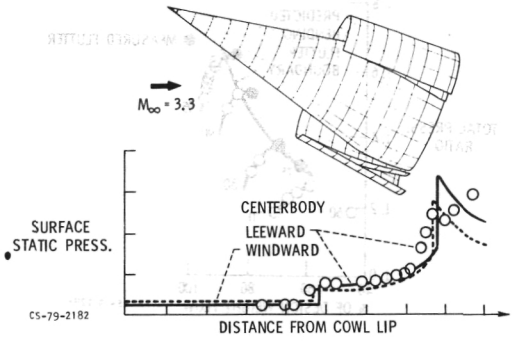


2-D POTENTIAL FLOW FINITE DIFFERENCE METHOD



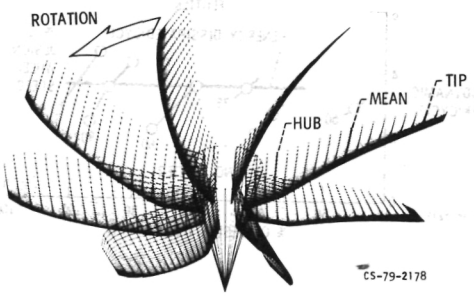
3-D METHOD OF CHARACTERISTICS

INLET AT 3° ANGLE OF ATTACK



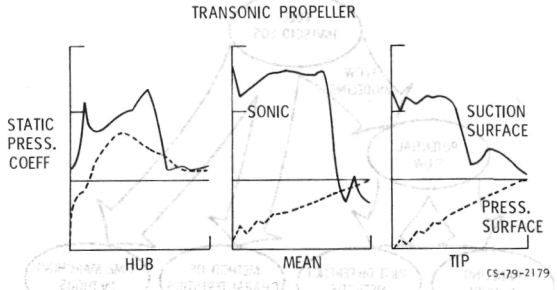
3-D TIME MARCHING METHOD

TRANSONIC PROPELLER; M_∞ = 0.8, M_{TIP} = 1.15



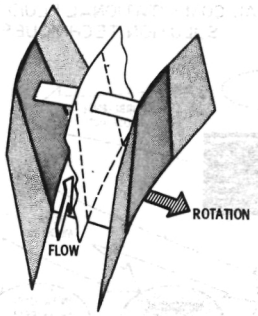
3-D TIME MARCHING METHOD

TRANSONIC PROPELLER



3-D TIME MARCHING METHOD

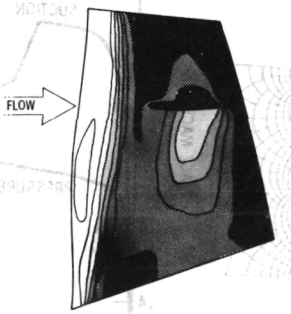
1800 fps ROTOR



MID-CHANNEL FLOW SURFACE CS-79-2280

3-D TIME MARCHING METHOD

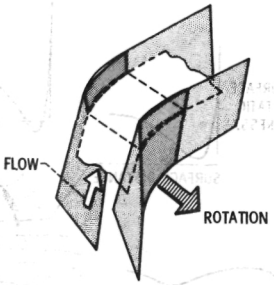
1800 fps ROTOR



PRESS. CONTOURS CS-79-2284

3-D TIME MARCHING METHOD

1600 fps ROTOR

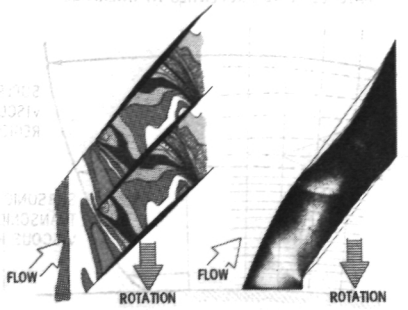


BLADE-TO-BLADE FLOW SURFACE

CS-79-2273

3-D TIME MARCHING METHOD

1600 fps ROTOR

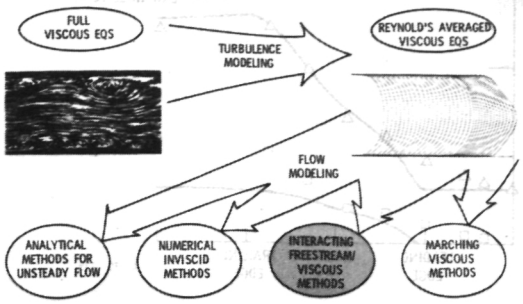


CALCULATED DENSITY CONTOURS

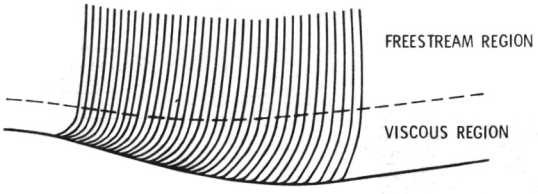
EXPERIMENTAL SHOCK LOCATIONS

CS-79-2288

INTERNAL COMPUTATIONAL FLUID MECHANICS SOLUTION TECHNIQUES



INTERACTING FREESTREAM/VISCOUS METHODS



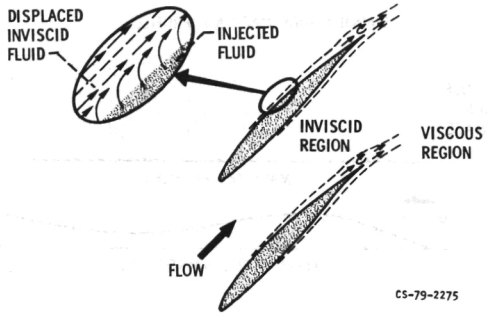
INTERACTION TECHNIQUES

BOUNDARY LAYER DISPLACEMENT OF INVISCID REGION

MATCHED FLUID PROPERTIES AT INTERFACE

INTERACTING INVISCID/VISCOUS METHOD

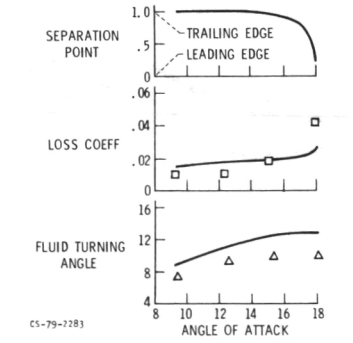
BOUNDARY LAYER DISPLACEMENT - 2-D CASCADE



CS-79-2275

INTERACTING INVISCID/VISCOUS METHOD

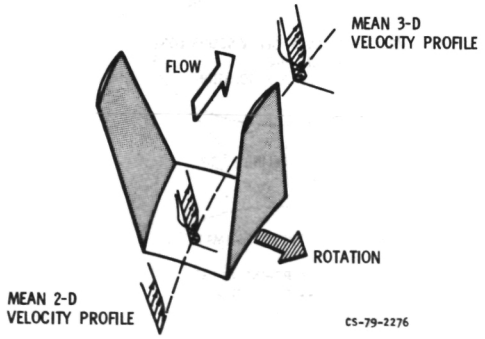
EXPERIMENTAL/ANALYTICAL COMPARISON - 2-D CASCADE



CS-79-2283

INTERACTING INVISCID/VISCOUS METHOD

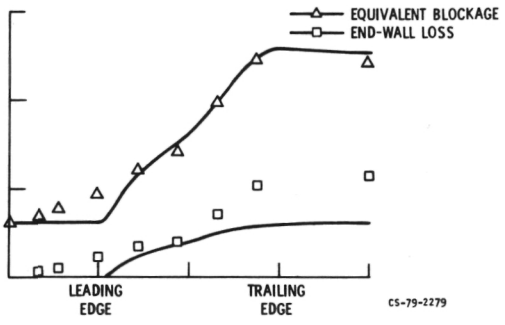
BOUNDARY LAYER DISPLACEMENT - BLADE-PASSAGE END-WALL



CS-79-2276

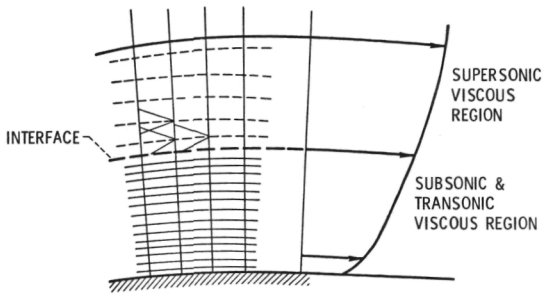
INTERACTING INVISCID/VISCOUS METHOD

EXPERIMENTAL/ANALYTICAL COMPARISON BLADE-PASSAGE END-WALL



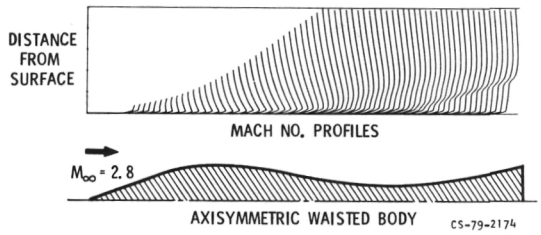
INTERACTING SUPERSONIC/SUBSONIC VISCOUS METHOD

MATCHED FLUID PROPERTIES AT INTERFACE

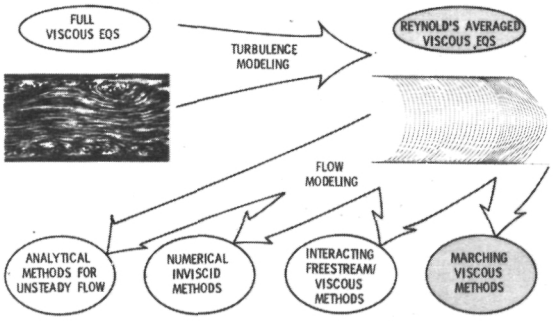


INTERACTING SUPERSONIC/SUBSONIC VISCOUS METHOD

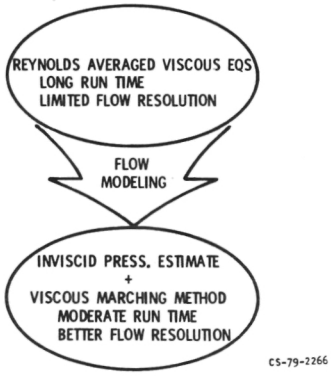
WAISTED BODY MACH NO. PROFILES



INTERNAL COMPUTATIONAL FLUID MECHANICS SOLUTION TECHNIQUES

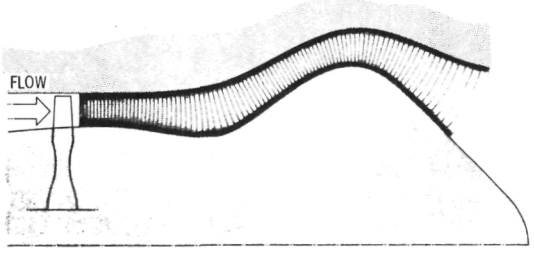


VISCOUS METHODS



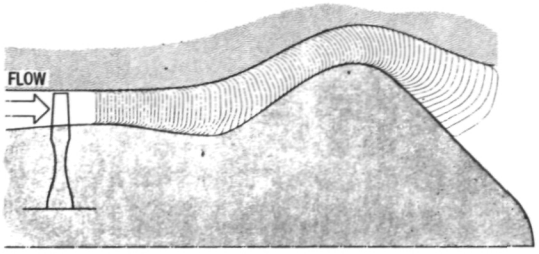
AXISYMMETRIC VISCOUS MARCHING METHOD

CURVED NOZZLE SOLUTION MESH



AXISYMMETRIC VISCOUS MARCHING METHOD

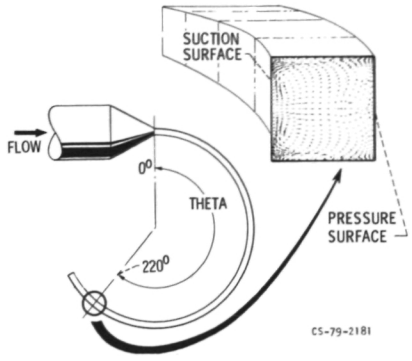
CURVED NOZZLE VELOCITY PROFILES



CS-79-2175

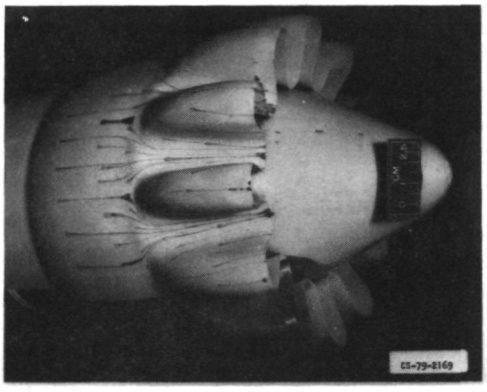
3-D VISCOUS MARCHING METHOD

CIRCULAR ARC DUCT



CS-79-2181

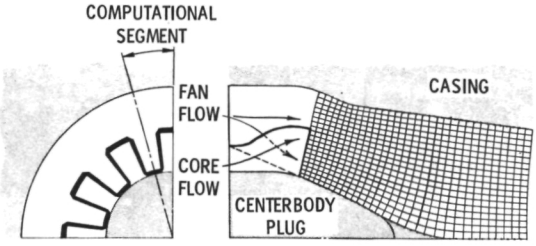
MIXER NOZZLE LOBE GEOMETRY



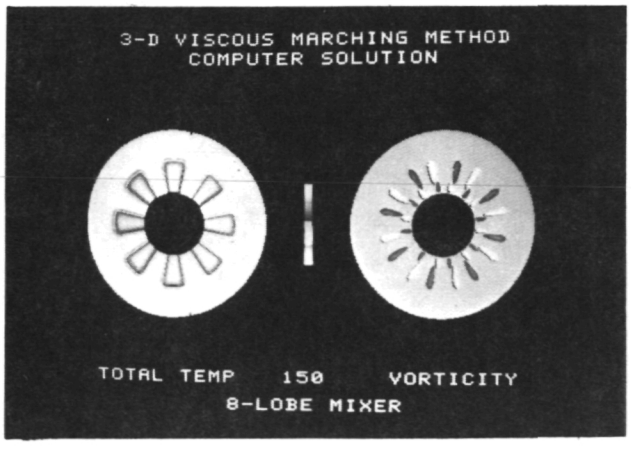
CS-79-2169

3-D VISCOUS MARCHING METHOD

MIXER NOZZLE SOLUTION MESH

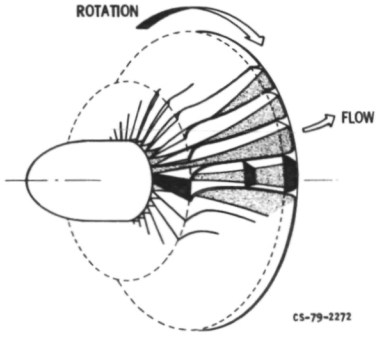


CS-79-2170



3-D FULL VISCOUS METHOD

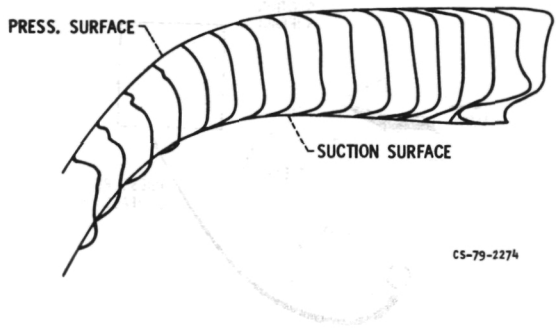
BLADE PASSAGE IN CENTRIFUGAL IMPELLER

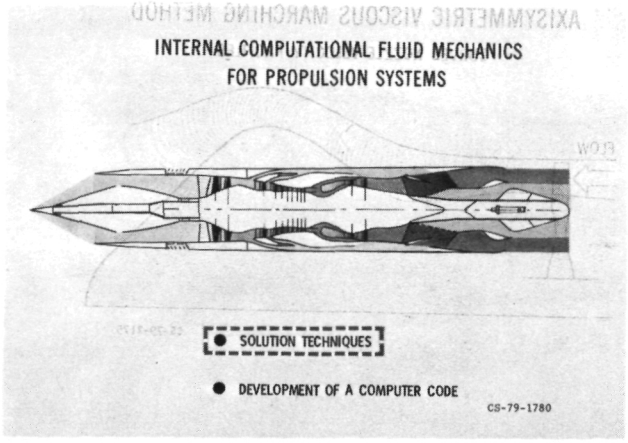


CS-79-2272

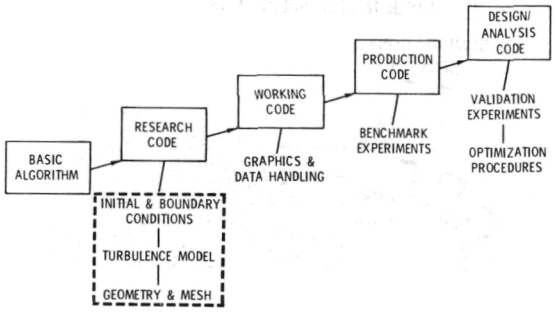
3-D FULL VISCOUS METHOD

VELOCITY PROFILES ON BLADE-TO-BLADE SURFACE

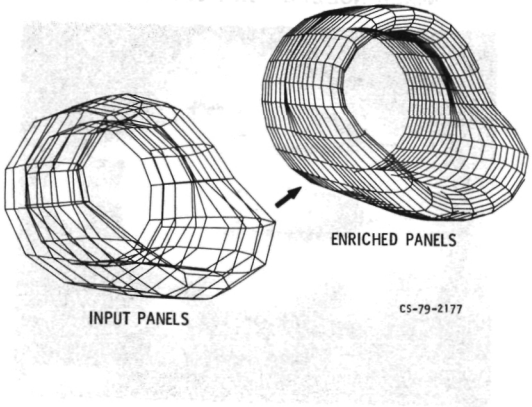




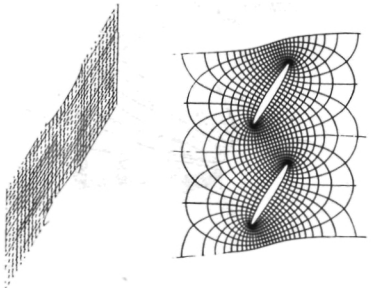
DEVELOPMENT OF A COMPUTER CODE



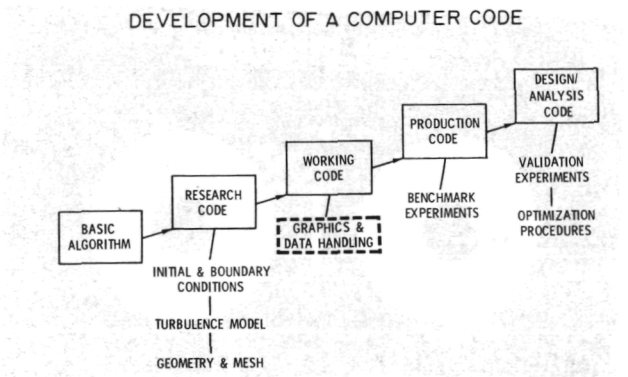
GEOMETRY ENRICHMENT



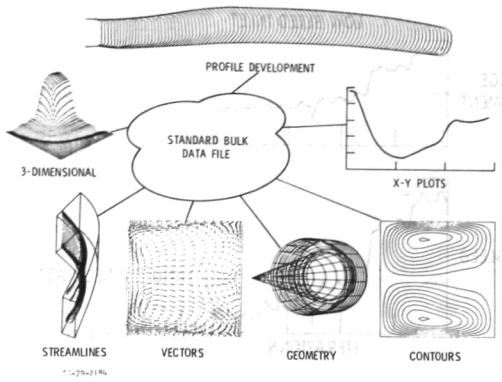
EFFECT OF MESH GEOMETRY
TRANSONIC CASCADE FLOW



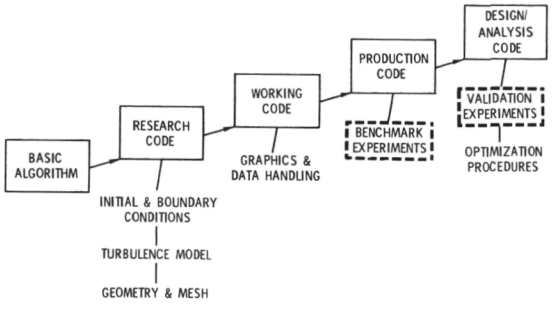
DEVELOPMENT OF A COMPUTER CODE



DATA HANDLING AND GRAPHICS



DEVELOPMENT OF A COMPUTER CODE



REQUIREMENTS OF BENCHMARK EXPERIMENTS

SIMPLIFY EXPERIMENT TO ISOLATE PARTICULAR FLOW PHENOMENON.

SIMPLIFY FLOW SITUATION (I.E., 2-D, LAMINAR, SUBSONIC) TO CHECK NUMERICAL ALGORITHM.

WELL DEFINED GEOMETRY, & BOUNDARY & INITIAL CONDITIONS.

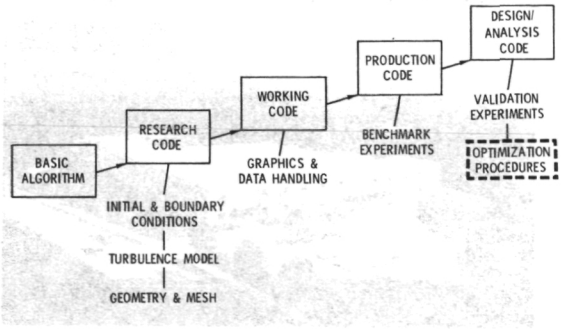
REDUNDANT MEASUREMENTS FOR CREDIBILITY.

WELL DOCUMENTED.

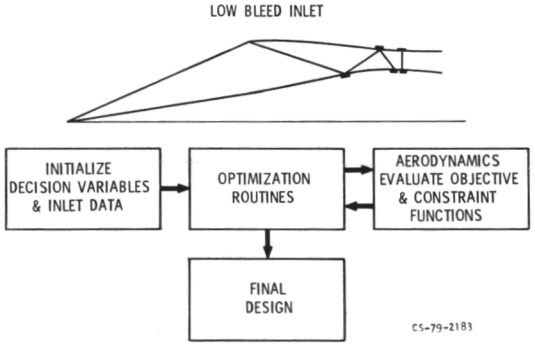
EASILY ACCESSIBLE.

CS-79-2263

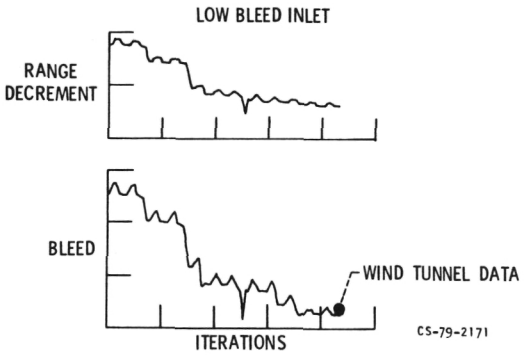
DEVELOPMENT OF A COMPUTER CODE



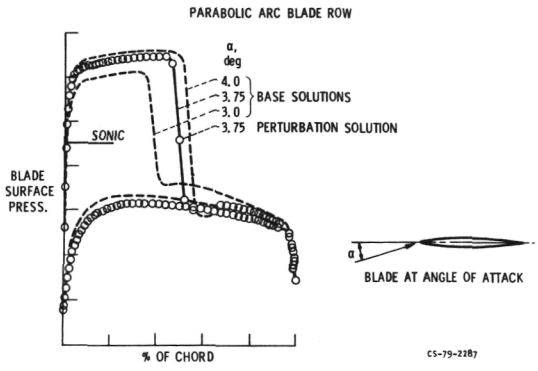
NUMERICAL OPTIMIZATION FOR DESIGN



NUMERICAL OPTIMIZATION FOR DESIGN



FAST PERTURBATION SOLUTIONS FOR DESIGN



GOALS OF INTERNAL COMPUTATIONAL FLUID MECHANICS

GOALS	BENEFITS
RAPID SIMULATION OF COMPLEX FLOW	REDUCED DESIGN COST
DETAILED FLOW FIELD DESCRIPTIONS	REDUCED DESIGN TIME
SIMULATION OF FLOWS THAT ARE EXPERIMENTALLY COSTLY	REDUCED DESIGN RISK
RAPID CONFIGURATION OPTIMIZATION	IMPROVED DESIGN

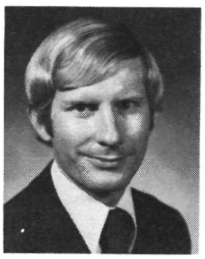
NASA LEWIS RESEARCH ANALYSIS CENTER

D7

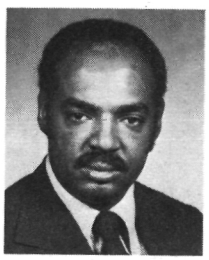
VII. TURBOMACHINERY TECHNOLOGY

Cavour H. Hauser, Chairman
Jeffrey E. Haas
Lonnie Reid
Francis S. Stepka

CAVOUR H. HAUSER began his Lewis career in 1944 after receiving a B.S. degree in mechanical engineering from the University of Minnesota. In 1949, he earned an M.S. degree in mechanical engineering from Case Institute of Technology. He has specialized in the aerodynamics of fans, compressors, and turbines and in the hydrodynamic design and application of pumps. Currently, he is Head of the Single Stage Compressor Section, Fluid System Components Division.



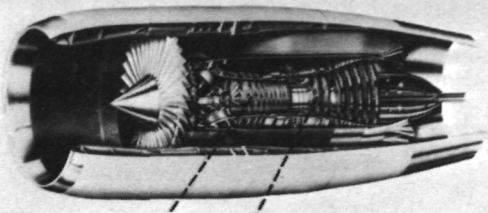
JEFFREY E. HAAS has been stationed at Lewis with the U.S. Army Propulsion Laboratory since 1970. A native of West Reading, Pennsylvania, he received a B.S. degree in aerospace engineering from the University of Pittsburgh in 1970 and an M.S. degree in mechanical engineering from the University of Toledo in 1975. As a member of the Small Turbine Section, Fluid System Components Division, he has specialized in small turbine research for advanced engine applications.



LONNIE REID is Head of the Small Compressor Section, Fluid System Components Division, at NASA Lewis, whose staff he joined in 1961 after receiving a B.S. degree in mechanical engineering from Tennessee State University. In 1973, he received an M.S. degree in mechanical engineering from the University of Toledo. He has specialized in fluid flow and compressor aerodynamics and currently is responsible for planning and developing research projects to improve the design and performance of small axial and centrifugal compressors.

FRANCIS S. STEPKA became a member of the NASA Lewis staff after receiving a B.S. degree in mechanical engineering from Carnegie-Mellon University. He subsequently earned an M.S. degree in aeronautical engineering from Case Western Reserve University and an M.S. degree in industrial engineering from the University of Toledo. At Lewis, he has specialized in and published numerous articles on heat transfer and turbine cooling research. In assignments with various Government organizations, including a Congressional committee, he has been involved in evaluating most of the Nation's advanced engines. He is a member of the Heat Transfer and Gas Turbine Committees of the ASME and is Head of the Turbine Cooling Section, Fluid System Components Division.

TURBOMACHINERY TECHNOLOGY GOALS



CORE COMPRESSOR
- HIGH PRESS. RATIO
- EFFICIENT
- PERFORMANCE RETENTION
- REDUCED NO. OF BLADES

HIGH PRESS. TURBINE
- HIGH TURBINE INLET TEMP
- DURABLE
- MIN. COOLANT FLOW
- EFFICIENT

TURBOMACHINERY PANEL TOPICS

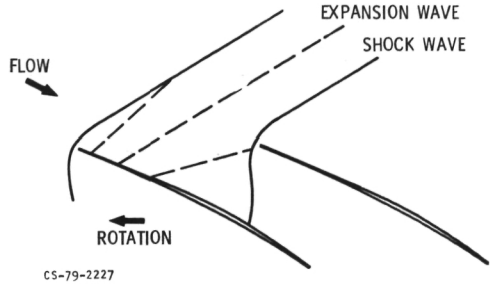
CORE COMPRESSOR
- INLET STAGES
  - LOW BLADE ASPECT RATIO
  - HIGH TIP SPEED
- MIDDLE & REAR STAGES
  - REDUCED LOSSES IN ENDWALL REGIONS
  - REDUCED TIP CLEARANCE LOSS

EXPERIMENTAL VERIFICATION OF ANALYTICAL CODES
- LASER DOPPLER VELOCIMETER

HIGH PRESS. TURBINE
- COOLING - HEAT TRANSFER
- THERMAL BARRIER COATING
- COOLING - AERODYNAMIC EFFECTS
- REDUCED TIP CLEARANCE LOSS

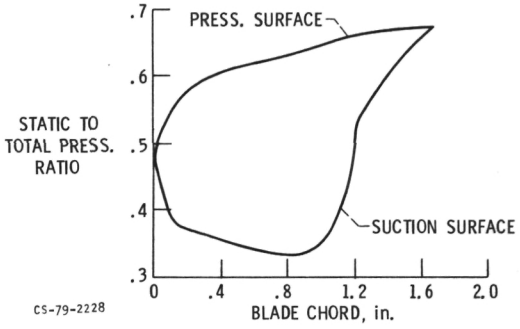
CS-79-2221

TRANSONIC COMPRESSOR FLOW MODEL



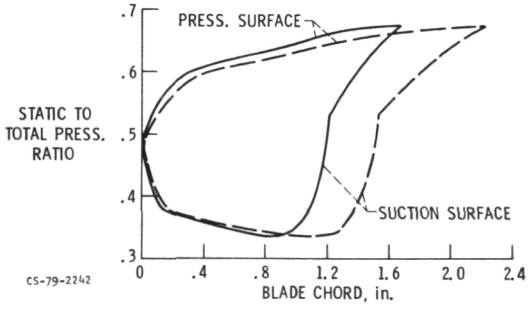
CS-79-2227

BLADE SURFACE PRESSURES



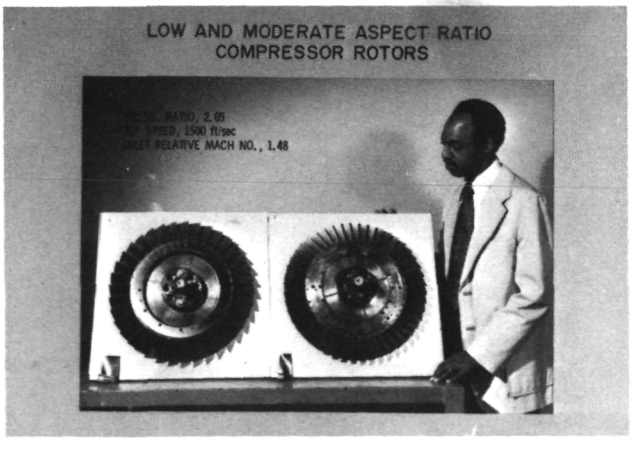
CS-79-2228

BLADE SURFACE PRESSURES



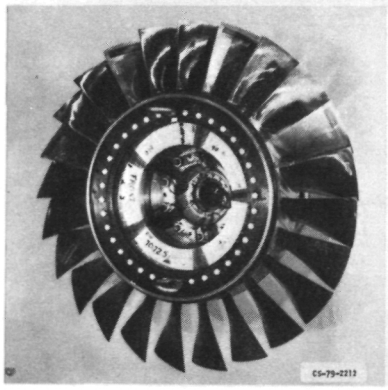
CS-79-2242

LOW AND MODERATE ASPECT RATIO COMPRESSOR ROTORS

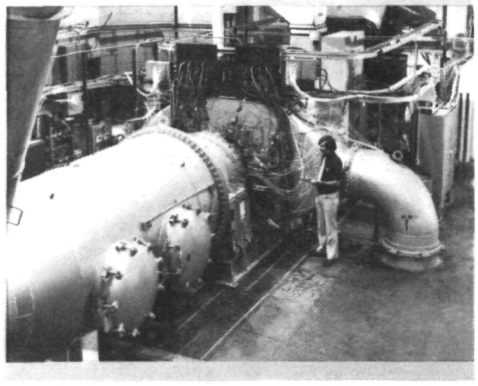


LOW ASPECT RATIO INLET STAGE ROTOR

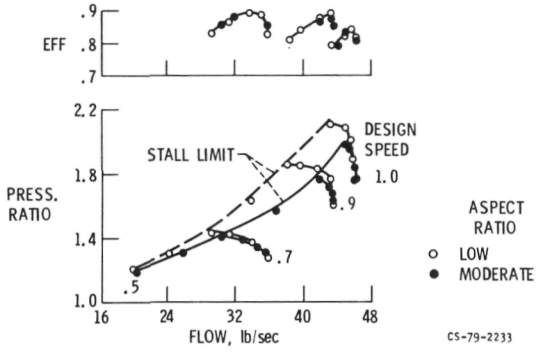
PRESS. RATIO, 1.87; TIP SPEED, 1450 ft/sec; INLET RELATIVE MACH NO., 1.3



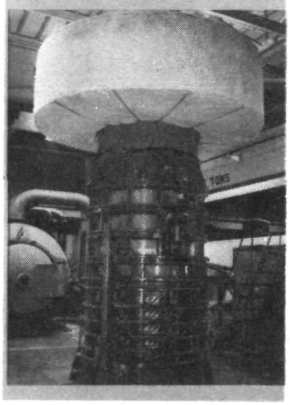
LEWIS SINGLE STAGE COMPRESSOR FACILITY



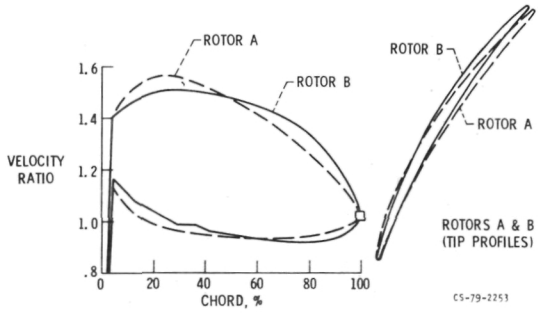
STAGE PERFORMANCE COMPARISON



LOW SPEED COMPRESSOR FACILITY

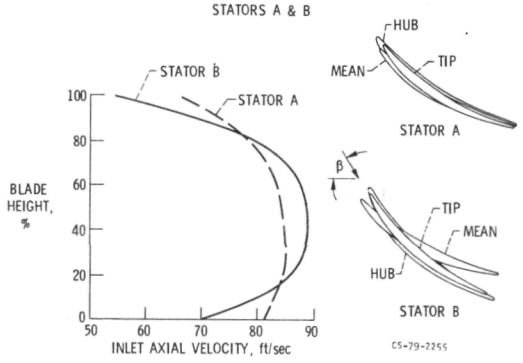


SURFACE VELOCITY COMPARISON

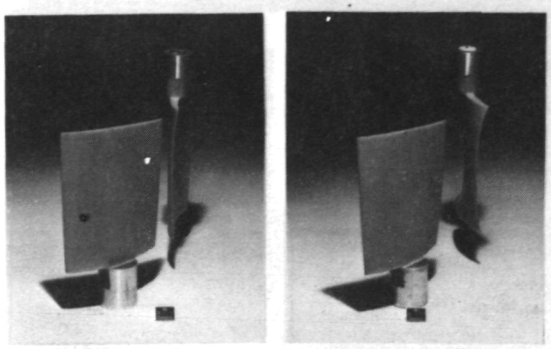


COMPARISON OF RADIAL VARIATION OF AXIAL VELOCITY

STATORS A & B



REAR STAGE BLADING

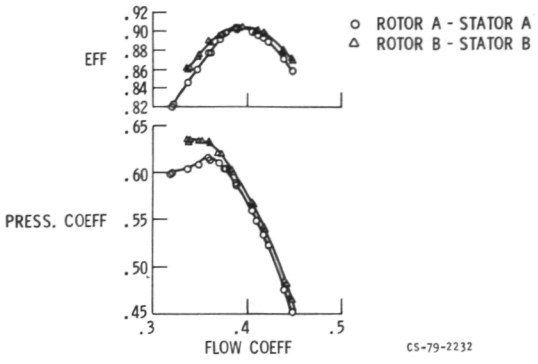


ROTOR A – STATOR A

ROTOR B – STATOR B

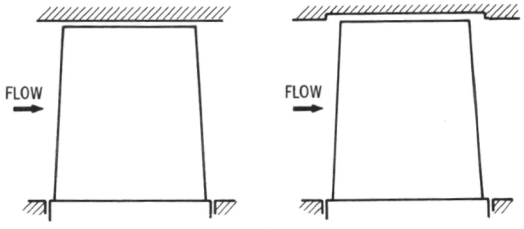
CS-79-2208

STAGE OVERALL PERFORMANCE



CS-79-2232

CASING WITH RECESSED CLEARANCE

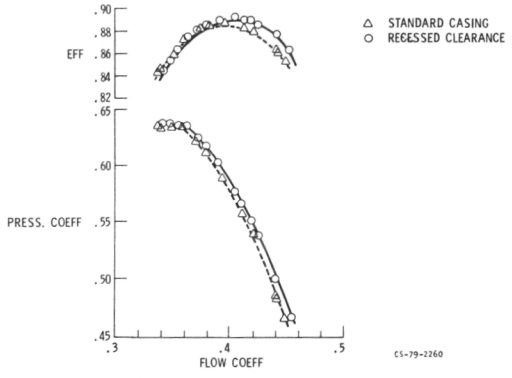


STANDARD CASING

RECESSED CLEARANCE

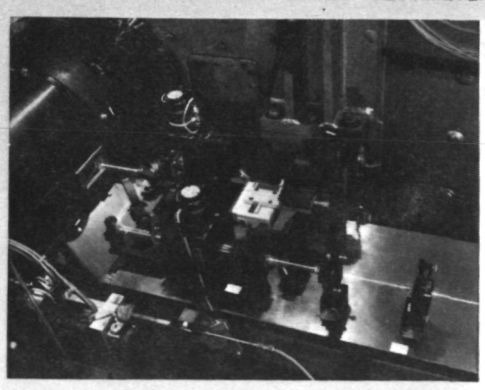
CS-79-2251

EFFECT OF RECESSED CLEARANCE

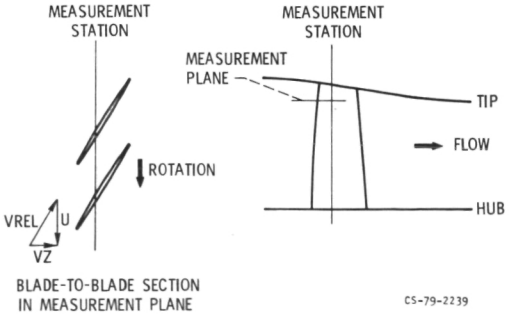


CS-79-2260

COMPRESSOR FACILITY WITH LASER VELOCIMETER



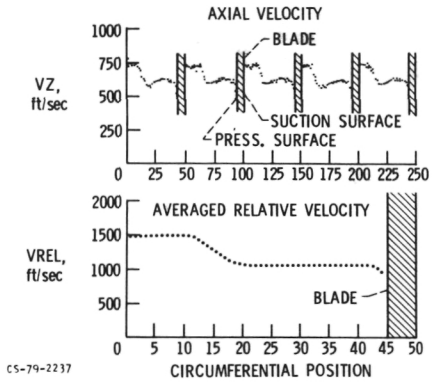
LDV MEASUREMENT LOCATIONS



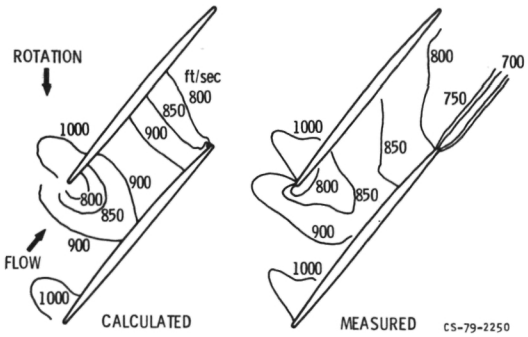
BLADE-TO-BLADE SECTION IN MEASUREMENT PLANE

CS-79-2239

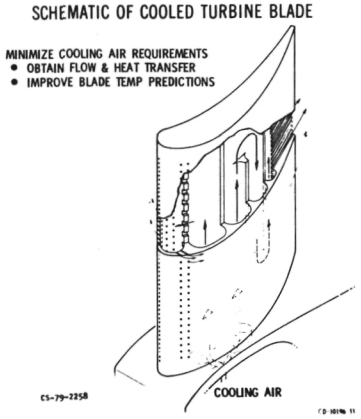
LDV VELOCITY MEASUREMENTS



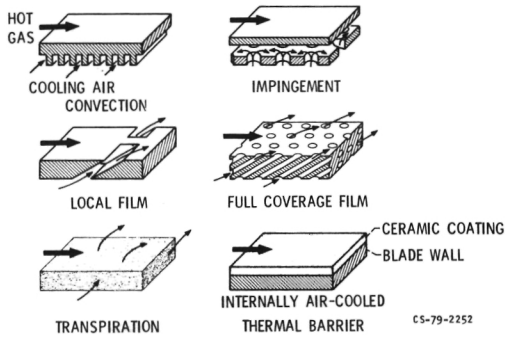
CALCULATED AND MEASURED VELOCITY CONTOURS



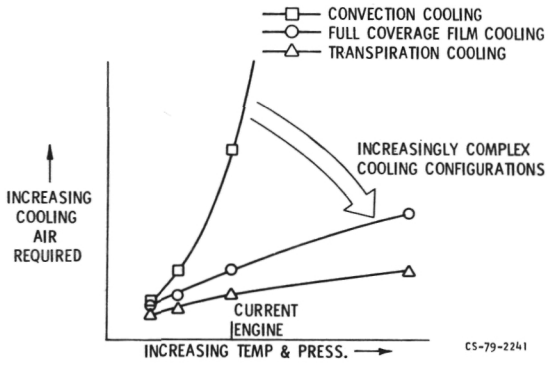
SCHEMATIC OF COOLED TURBINE BLADE



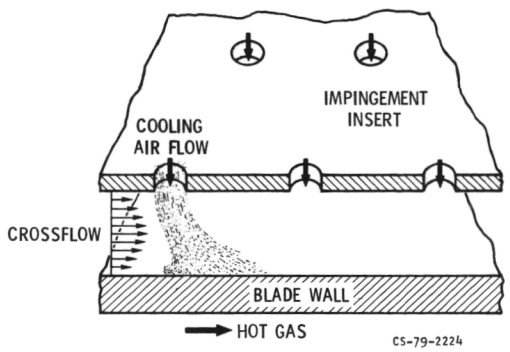
TURBINE BLADE WALL COOLING TECHNIQUES



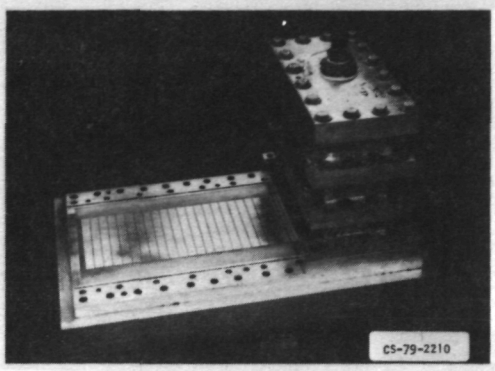
TURBINE COOLING REQUIREMENTS



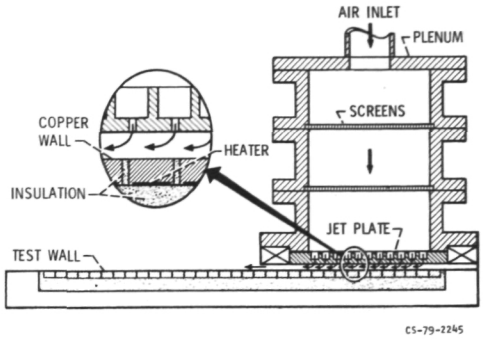
IMPINGEMENT COOLING



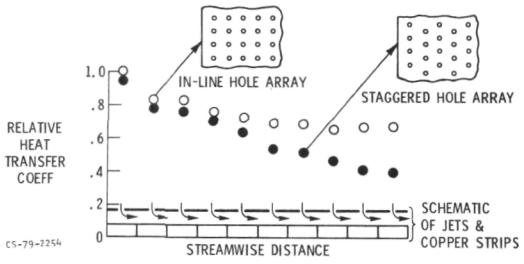
IMPINGEMENT COOLING APPARATUS



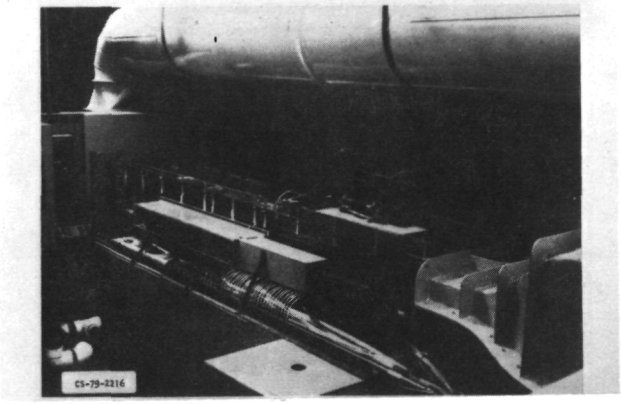
SCHEMATIC OF IMPINGEMENT COOLING APPARATUS



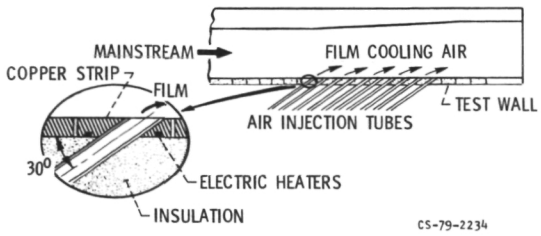
IMPINGEMENT COOLING HEAT TRANSFER



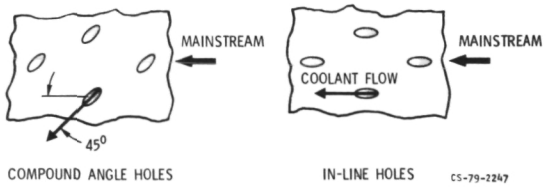
FILM COOLING APPARATUS



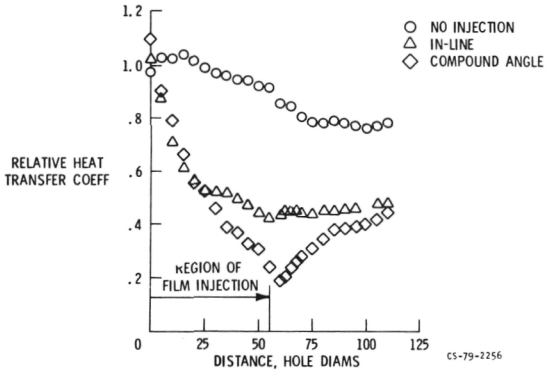
SCHEMATIC OF FILM COOLING APPARATUS



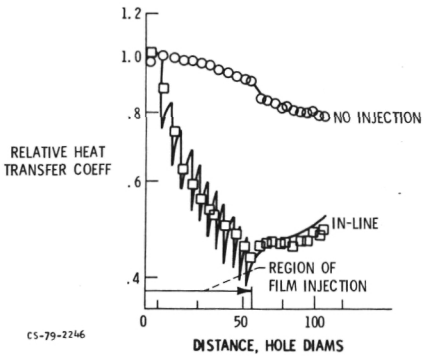
FILM COOLING HOLE ARRAYS



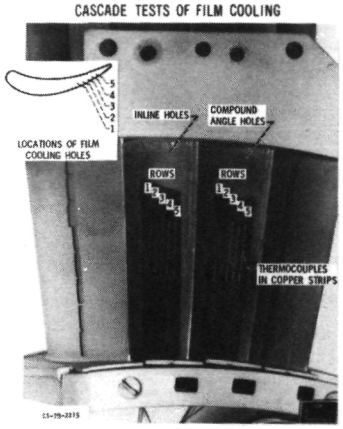
EFFECT OF FILM COOLING



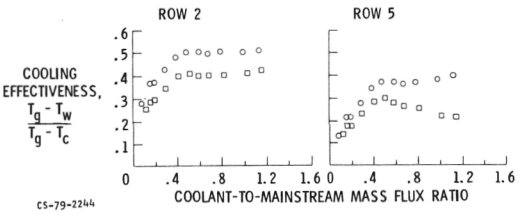
EXPERIMENTAL AND PREDICTED FILM COOLING



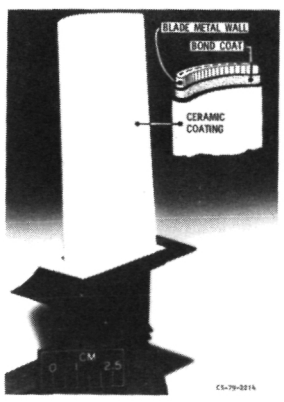
CASCADE TESTS OF FILM COOLING



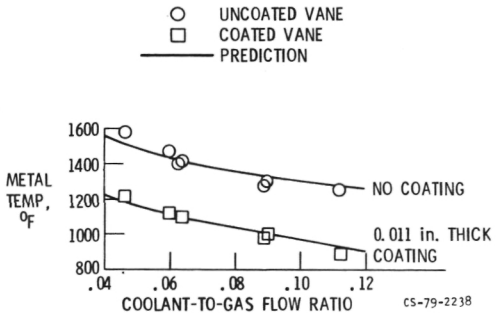
FILM COOLING OF TURBINE VANE IN CASCADE



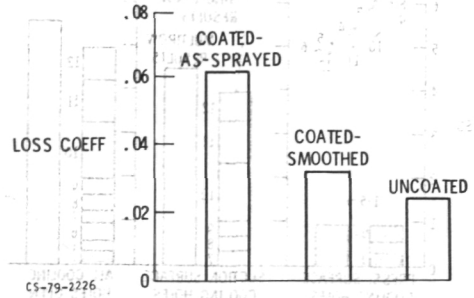
THERMAL BARRIER COATED TURBINE BLADE



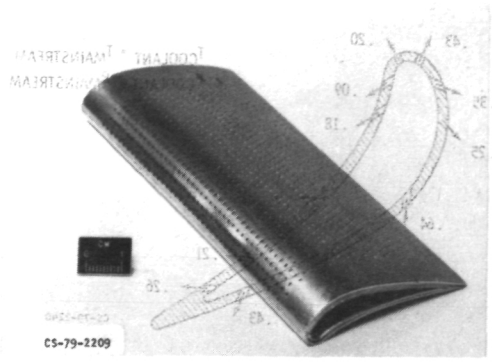
EFFECT OF THERMAL BARRIER COATING ON VANE METAL TEMPERATURES



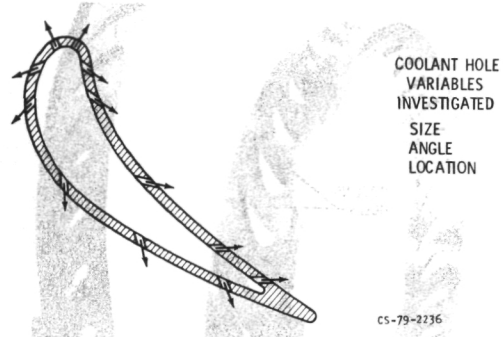
EFFECT OF THERMAL BARRIER COATING ON VANE LOSSES



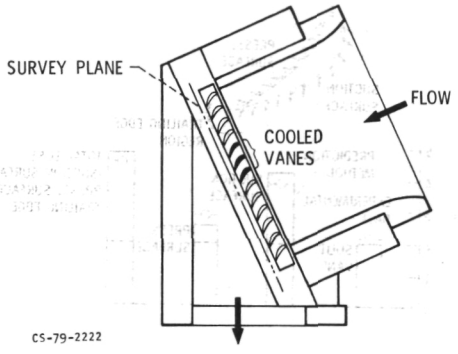
FULL-FILM COOLED VANE



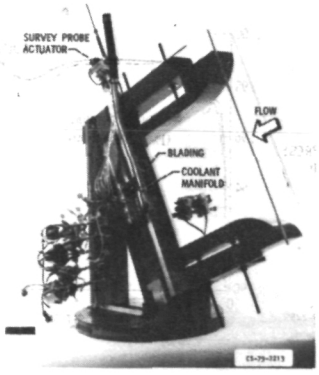
FILM-COOLED VANE TEST PROGRAM



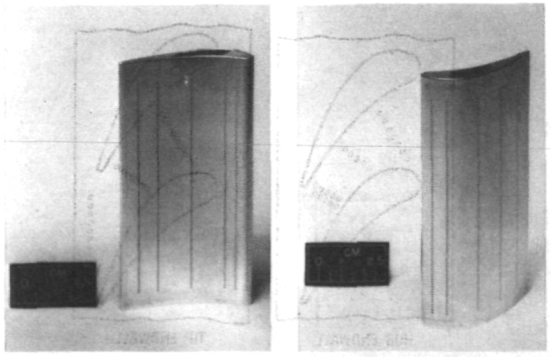
STATOR VANE CASCADE



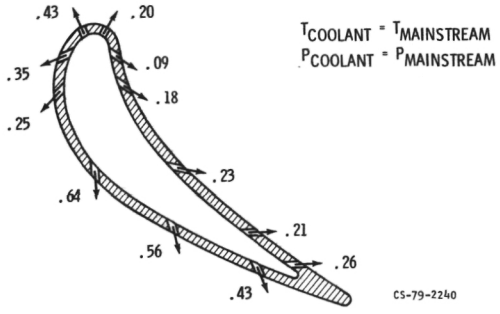
STATOR VANE CASCADE



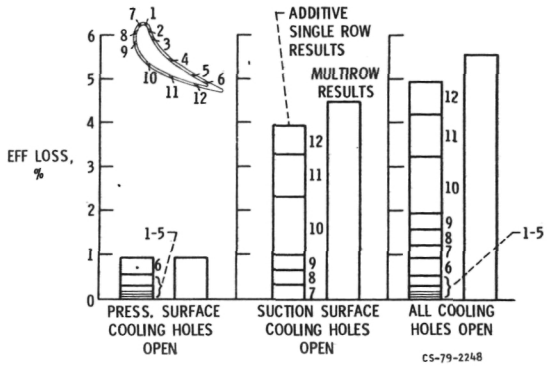
FILM-COOLED VANE



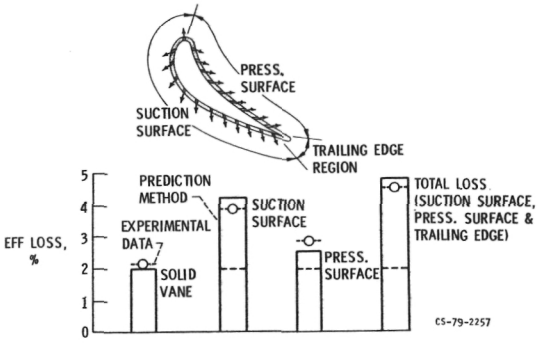
EFFICIENCY LOSS FOR 1% COOLING AIR EJECTION



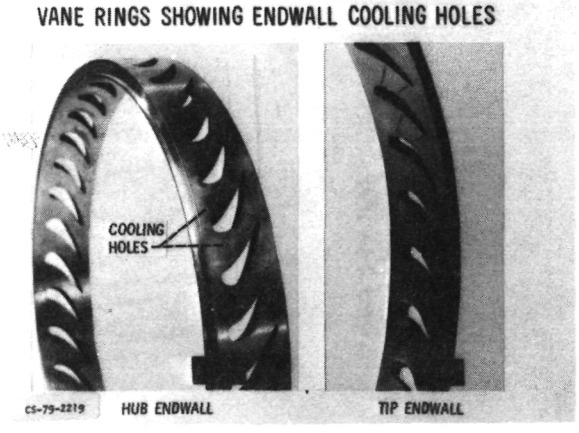
ADDITIVE FILM COOLING HOLE LOSSES



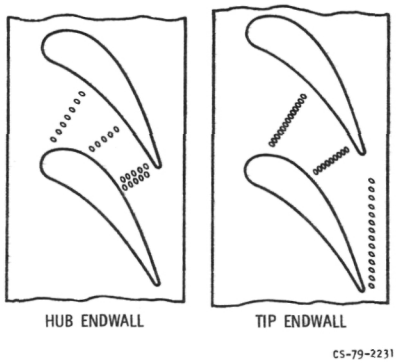
EXPERIMENTAL AND PREDICTED FILM COOLING LOSSES



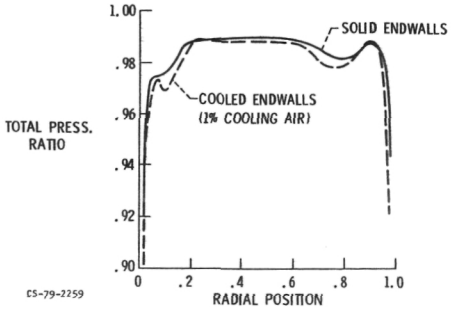
VANE RINGS SHOWING ENDWALL COOLING HOLES



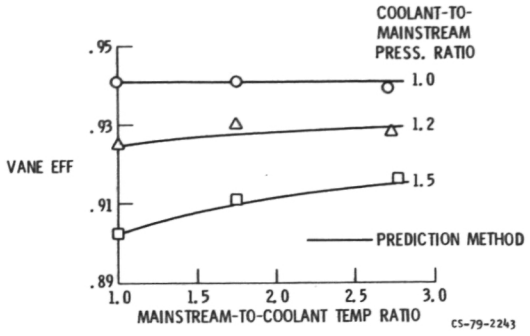
LOCATION OF ENDWALL COOLING HOLES



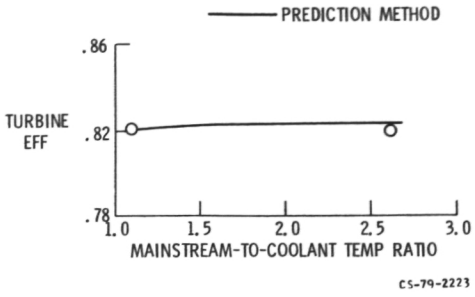
VANE TOTAL PRESSURE RATIO WITH ENDWALL COOLING AIR



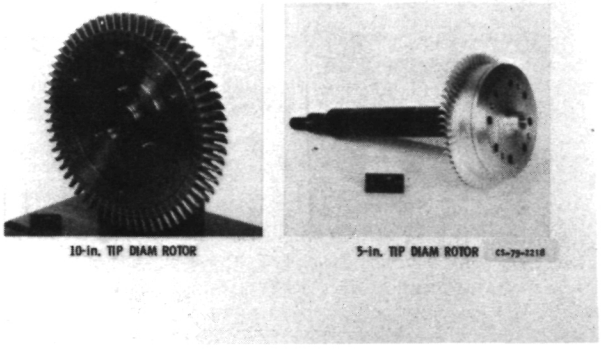
EXPERIMENTAL AND PREDICTED VANE EFFICIENCIES



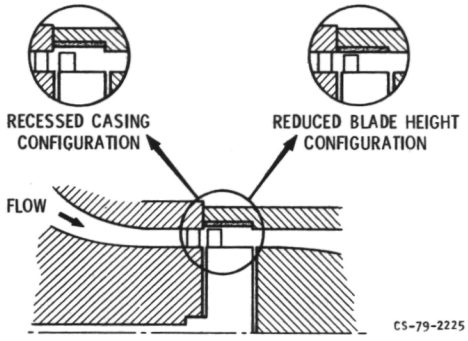
EXPERIMENTAL AND PREDICTED TURBINE EFFICIENCIES



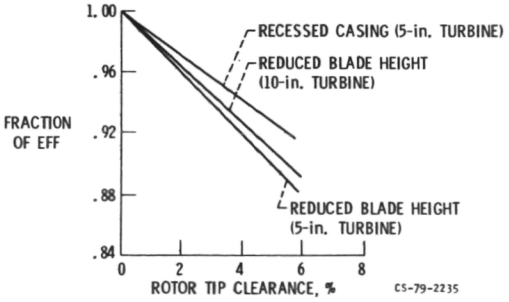
TURBINE ROTORS USED IN TIP CLEARANCE INVESTIGATIONS



TIP CLEARANCE CONFIGURATIONS



EFFECT OF ROTOR TIP CLEARANCE ON TURBINE PERFORMANCE



D8

VIII. MECHANICAL COMPONENTS

William J. Anderson, Chairman

Robert C. Bill

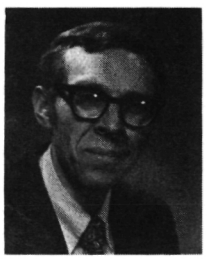
John J. Coy

David P. Fleming

WILLIAM J. ANDERSON, Chief of the Mechanical Components Branch, Fluid System Components Division, joined the NASA Lewis staff in 1950. A native of New York City, he has a B.S. degree in mechanical engineering from MIT and an M.S. degree in aeronautical engineering from Case Western Reserve University. He has specialized in research on bearing problems associated with aircraft turbine engines and rocket engine turbopumps and is currently responsible for research on bearings, gears, seals, rotor dynamics, and transmissions.

ROBERT C. BILL, a native of New Jersey, obtained a B.S. degree in mechanical engineering from the University of Delaware in 1966 and a Ph.D. degree in mechanical engineering from the University of Michigan in 1970. Since 1970, he has been a member of the U.S. Army Propulsion Laboratory at NASA Lewis, working with the Mechanical Components Branch, Fluid System Components Division. He is actively engaged in research on ceramic seals, friction and wear, and fretting.

JOHN J. COY has been on the staff of the NASA Lewis Bearing, Gearing, and Transmission Section of the Fluid System Components Division since 1974. He is employed by the U.S. Army Propulsion Laboratory and is currently responsible for helicopter transmission systems and dynamics research. He earned B.S., M.S., and Ph.D. degrees in mechanical engineering from the University of Cincinnati. A licensed professional engineer in the State of Ohio, he is a member of the ASME Power Transmission and Gear Committee as well as head of that committee's technical paper review. Author or coauthor of over 18 technical papers, he has been a technical consultant for NASA and other Government agencies.



DAVID P. FLEMING has worked at NASA Lewis since 1966. A native of Minnesota, he attended the University of Minnesota, where he received B.S., M.S., and Ph.D. degrees in mechanical engineering. As a member of the Seals and Rotor Dynamics Section, Fluid System Components Division, he has conducted and managed research on fluid film bearings, rotor dynamics, and seals.

MECHANICAL COMPONENTS

BEARINGS

GEARS

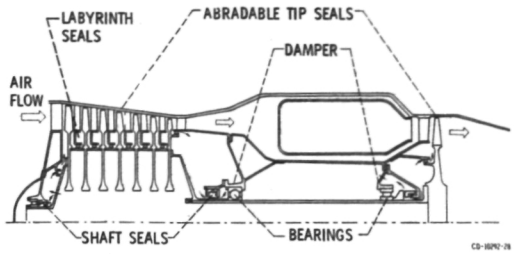
SEALS

ROTOR DYNAMICS (HIGH SPEED BALANCING, DAMPERS)

CS-79-1954

MECHANICAL COMPONENTS AREAS OF RESEARCH

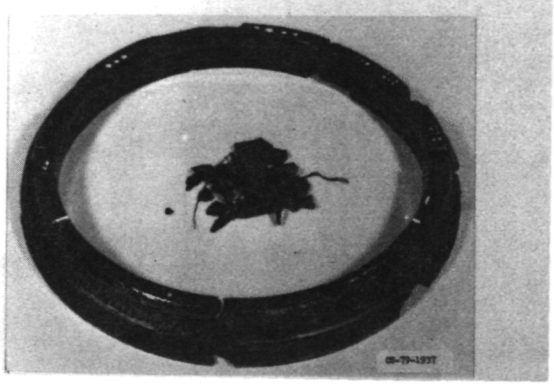
TYPICAL DAMPER LOCATIONS



CS-79-1975

FRACTURED INNER RING FROM BEARING

RUN AT 3 MILLION DN



CS-79-1937

TURBINE ENGINES	TRANSMISSIONS
HIGH SPEED BEARINGS	GEAR FAILURE MODES
LUBRICANT FILTRATION	GEAR PITTING LIFE
SHAFT SEALS	HIGH CONTACT RATIO GEARS
CERAMIC GAS PATH SEALS	GEAR LUBRICATION
HIGH SPEED BALANCING	TAPERED ROLLER BEARINGS
ELASTOMER DAMPERS	

CS-79-1972

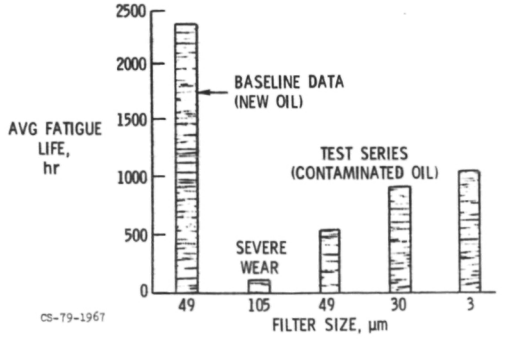
AIRCRAFT TURBINE ENGINE

BEARING & SEAL REQUIREMENTS

ELEMENT	STATE OF THE ART	REQUIREMENTS 1980'S	PROBLEMS
BALL & ROLLER	~2.4 MILLION DN	3 TO 3.3 MILLION DN	1. MATERIAL FRACTURE TOUGHNESS 2. LUBRICATION SYSTEM CLEANLINESS
SHAFT SEALS	450 ft/sec 130 psi ΔP	700-800 ft/sec 300-400 psi	1. HEAT GENERATION 2. WEAR
GAS PATH SEALS	METAL SHROUDS - COOLED TURBINE SEALS, LOW RUB TOLERANCE, BLADE WEAR, LARGE TIP CLEARANCES	ABRADABILITY, THERMAL SHOCK RESISTANCE, EROSION RESISTANCE	1. CERAMIC METAL BONDING 2. STRESS CONTROL 3. ROTOR MOTION CONTROL

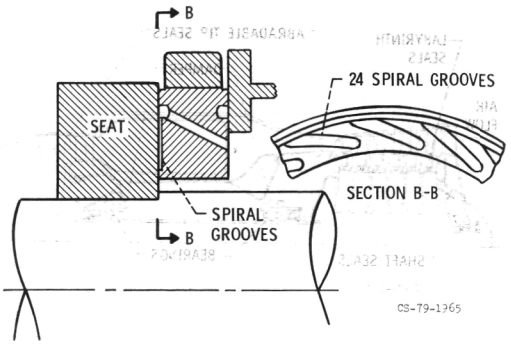
CS-79-1982

EFFECT OF FILTRATION ON BEARING LIFE

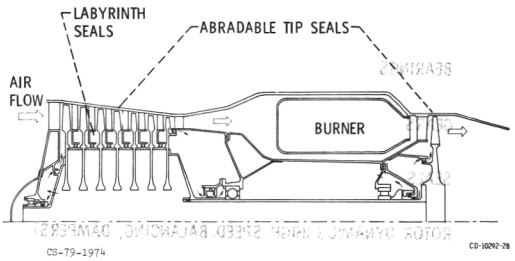


CS-79-1967

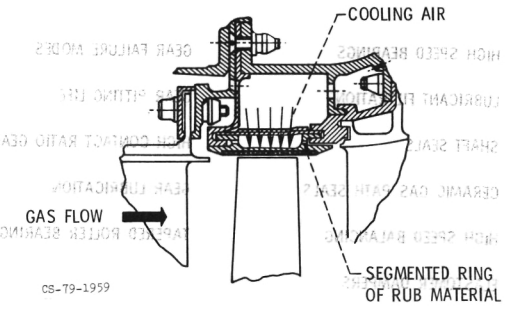
SPIRAL GROOVE SELF-ACTING SEAL



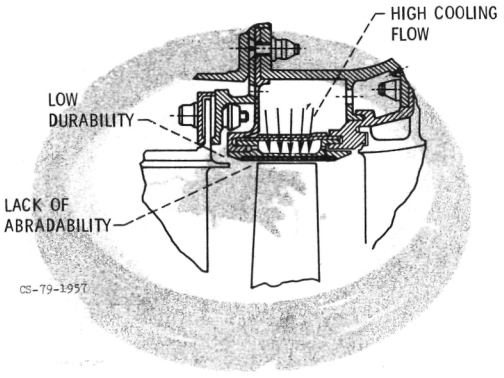
GAS PATH SEALING



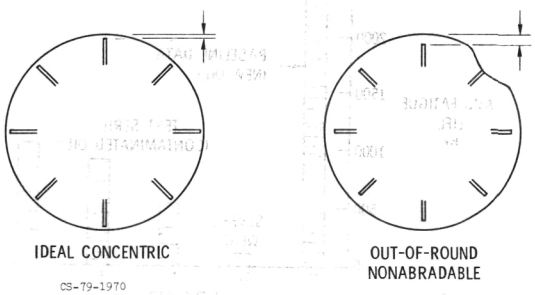
TURBINE GAS PATH SEALING



TURBINE GAS PATH SEALING PROBLEMS



TURBINE BLADE TIP CLEARANCE

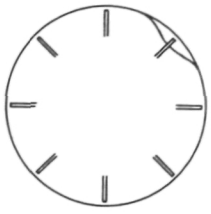


EFFECT OF TURBINE TIP CLEARANCE

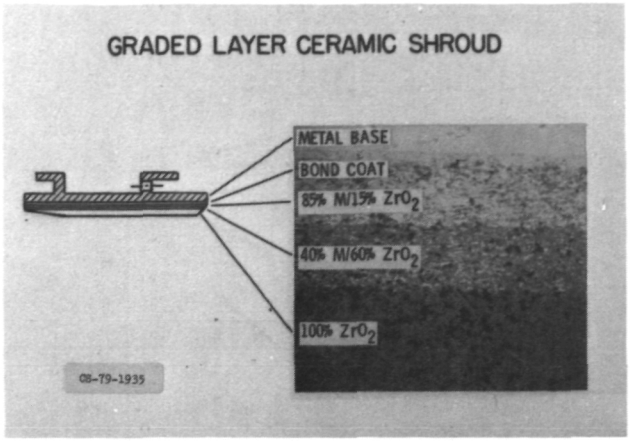
Δ TIP CLEARANCE	1% BLADE HEIGHT
Δ SFC	1.5 TO 2% OR ~150 000 000 gal/yr

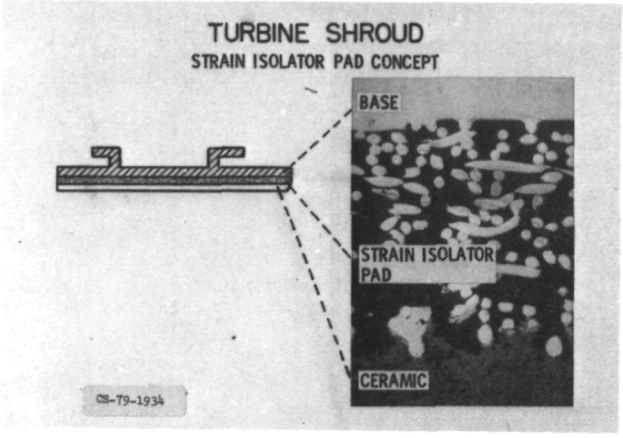
CS-79-1947

ABRADABLE TURBINE SHROUD CLEARANCE

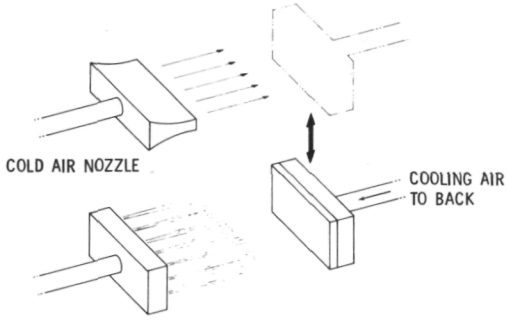


OUT-OF-ROUND ABRADABLE CS-79-1963



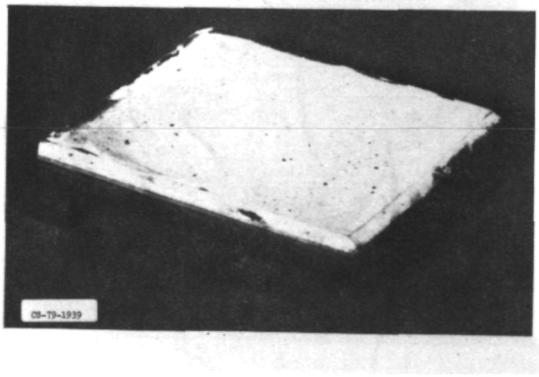


THERMAL CYCLING TEST

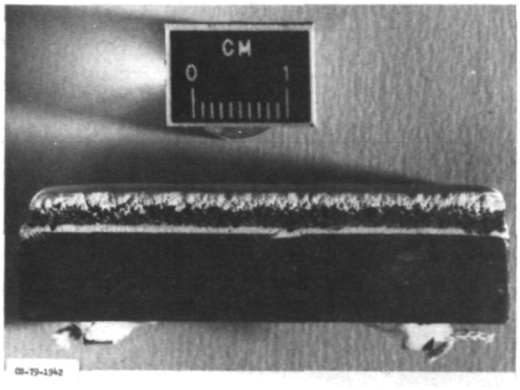


CS-79-1961

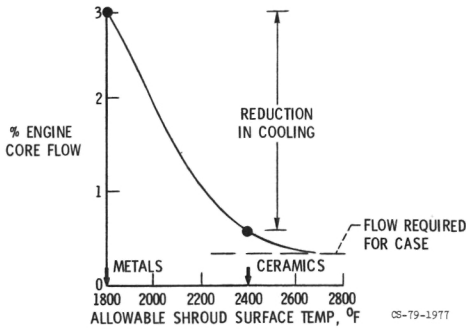
GRADED LAYER CERAMIC SHROUD



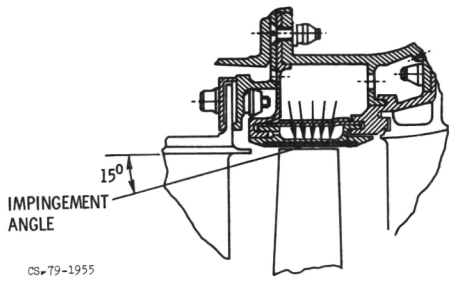
STRAIN ISOLATOR PAD SHROUD



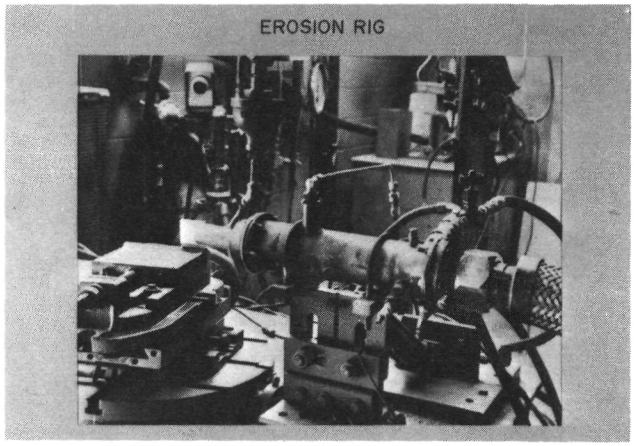
COOLING FLOW REQUIREMENTS



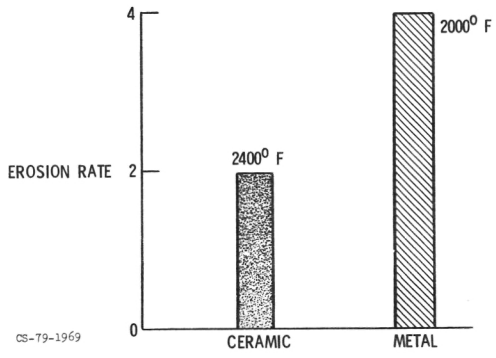
TURBINE SHROUD EROSION



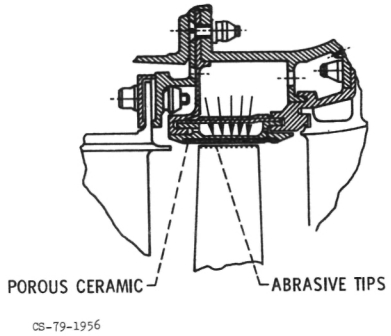
EROSION RIG



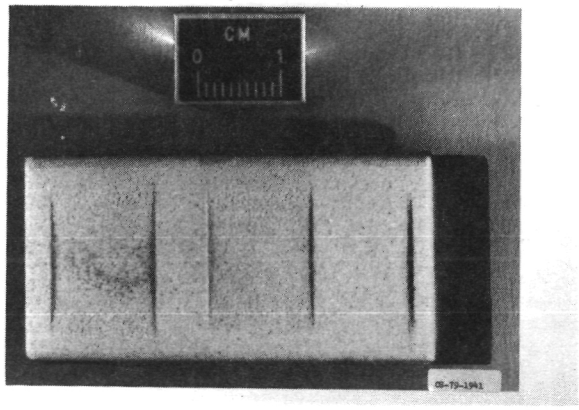
EROSION RATE



ABRADABLE TIP SEALING



ABRADABLE CERAMIC



BENEFITS OF CERAMIC TURBINE SEALING

REDUCED COOLING REQUIREMENTS

IMPROVED DURABILITY & ABRADABILITY

SFC REDUCTION OF 2 TO 4%

CS-79-1944

ROTOR DYNAMICS OBJECTIVES

1. LOW VIBRATIONAL AMPLITUDE
2. LOW BEARING FORCES
3. LOW MATERIAL STRESS

CS-79-1953

PROBLEMS INCREASED BECAUSE OF

LIGHTER, MORE FLEXIBLE STRUCTURES

HIGHER SPEEDS

MANY ROTORS OPERATE ABOVE BENDING CRITICAL SPEEDS

CS-79-1952

BENDING CRITICAL SPEED

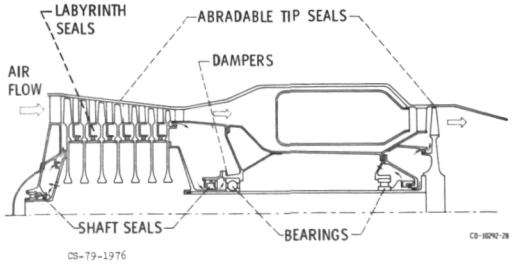
CS-79-1962

HOW TO RUN SUPERCRITICALLY

1. BALANCE ROTOR ACCURATELY
2. RUN THROUGH CRITICAL RAPIDLY
3. MODIFY SYSTEM TO REDUCE ROTOR AMPLITUDES & BEARING FORCES

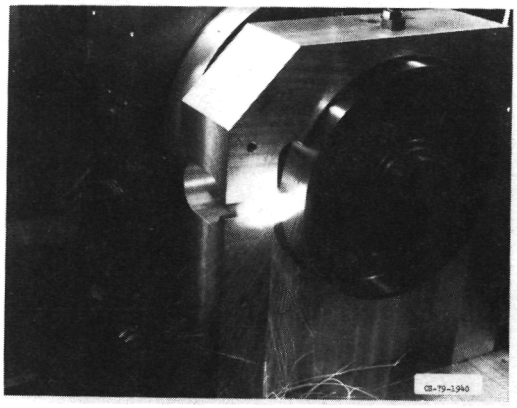
CS-79-1950

MECHANICAL COMPONENTS AREAS OF RESEARCH

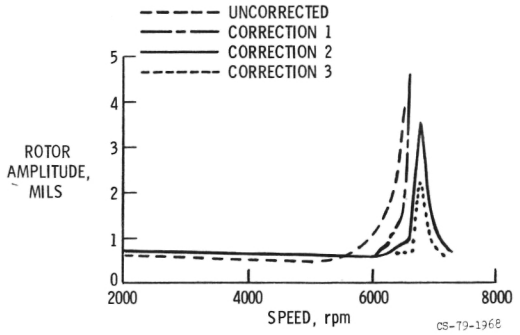


CS-79-1976

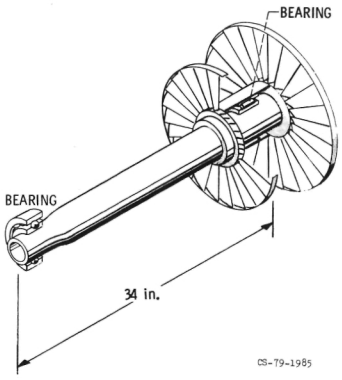
LASER REMOVING METAL FROM TEST ROTOR



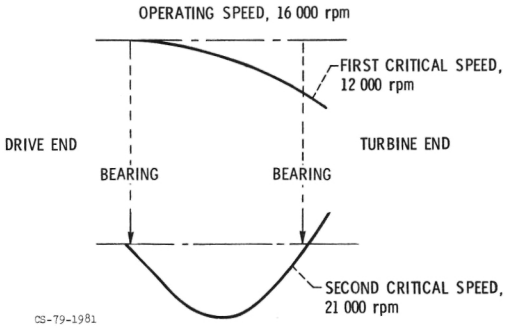
RESPONSE OF TEST ROTOR TO LASER BALANCING



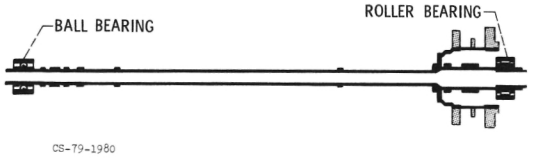
T55 POWER TURBINE ASSEMBLY



T55 POWER TURBINE CRITICAL SPEED MODE SHAPES



POWER TURBINE OF CURRENT TECHNOLOGY TURBOSHAFT ENGINE



APPLICATIONS OF COMPUTER-LASER BALANCING

DIRECT REPLACEMENT OF PRESENT COMPONENT BALANCING

IN-PLACE BALANCING (REQUIRES DESIGN CONSIDERATION)
- ACCESS PORTS
- SACRIFICIAL MATERIAL
- PERMANENTLY-INSTALLED SENSORS

REBALANCING INSTALLED ENGINE
- SMOOTHER-RUNNING ENGINE
- FEWER UNSCHEDULED REMOVALS
- EXTENDED TBO

BEARING SUPPORT DAMPERS

ABSORB VIBRATIONAL ENERGY

REDUCE ROTOR AMPLITUDE & BEARING FORCES

PROVIDE FOR SAFE SHUTDOWN AFTER LOSING TURBINE BLADE

LESS STRINGENT BALANCING REQUIREMENT

CS-79-1949

DAMPER TYPES

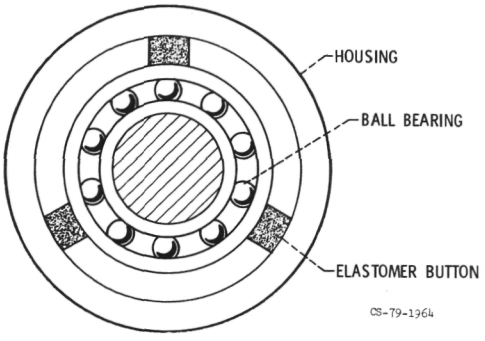
RUBBING FRICTION

OIL SQUEEZE FILM (HYDRODYNAMIC)

ELASTOMETRIC

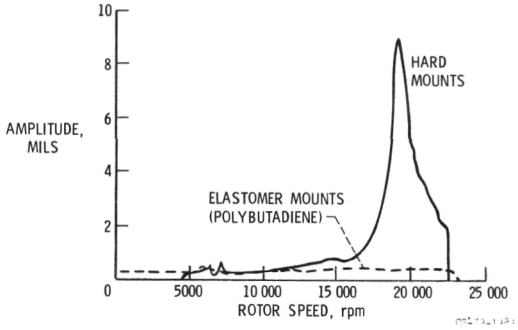
CS-79-1948

ELASTOMERIC DAMPER

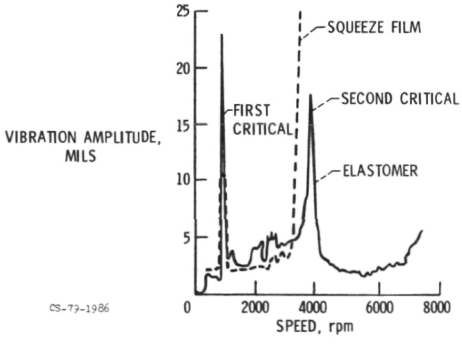


CS-79-1964

VIBRATION AMPLITUDE WITH ELASTOMER AND RIGID SUPPORTS



VIBRATION AMPLITUDE OF SUPERCRITICAL DRIVE SHAFT



CS-79-1986

ELASTOMERIC DAMPERS

ADVANTAGES
- SELF-CONTAINED
- SIMPLE DESIGN
- DIMENSIONAL TOLERANCES NOT CRITICAL
- NO STIFFNESS INCREASE WITH AMPLITUDE

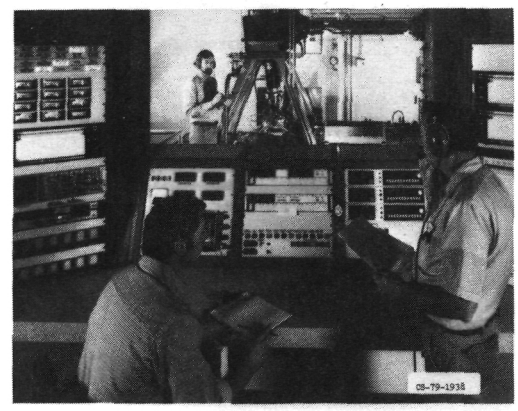
LIMITATIONS
- OIL COMPATABILITY
- AGING
- TEMP

CS-79-1946

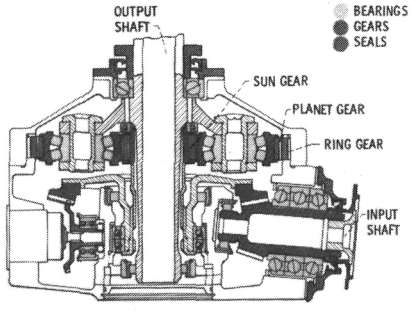
TRANSMISSION TECHNOLOGY GOALS

- INCREASED LIFE
- INCREASED RELIABILITY
- *REDUCED MAINTENANCE INTERVALS*
- LOWER WEIGHT
- HIGHER TEMP OPERATION
- IMPROVED LUBRICATION
- INCREASED EFF
- REDUCED NOISE & VIBRATION

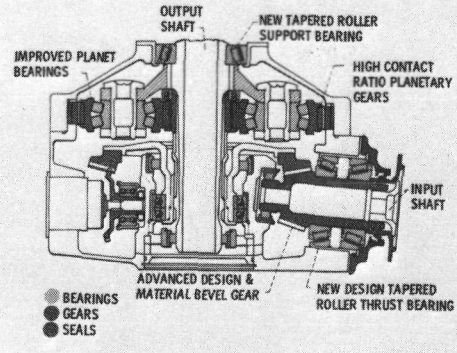
CS-79-1945

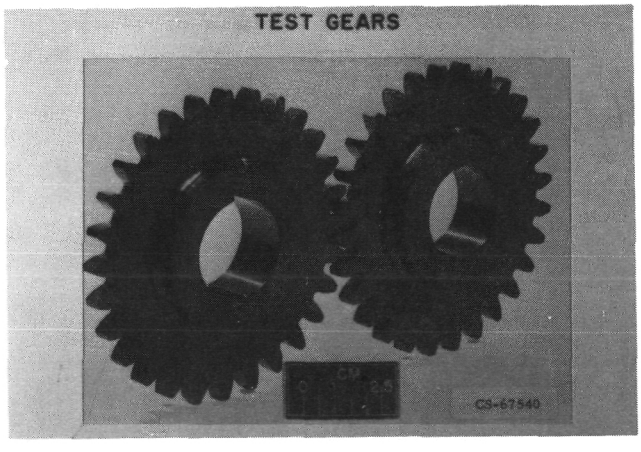


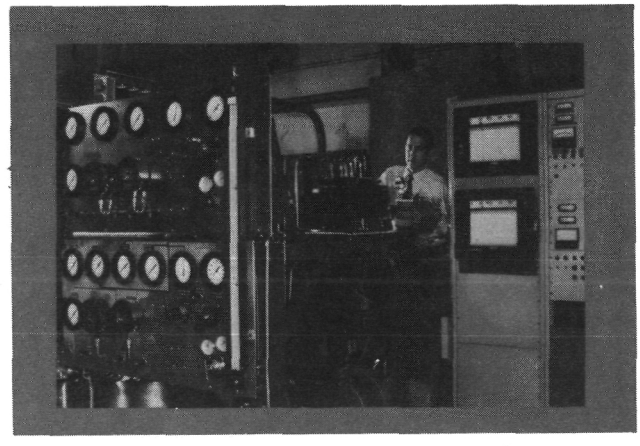
HELICOPTER TRANSMISSION WITH STANDARD BEARINGS AND GEARS



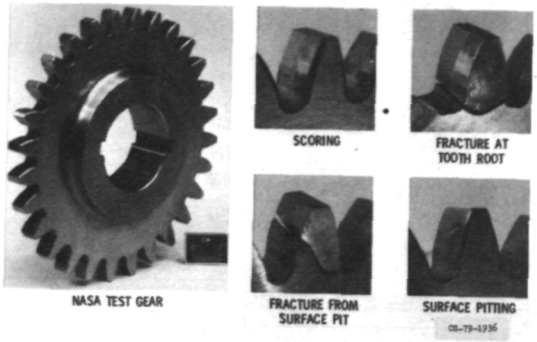
HELICOPTER TRANSMISSION WITH ADVANCED BEARINGS AND GEARS



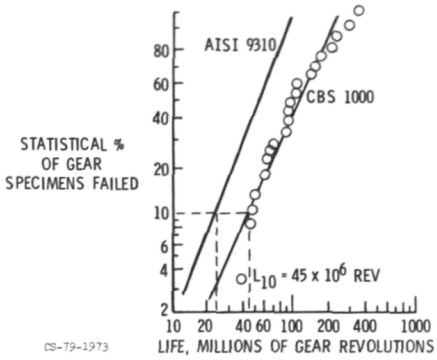




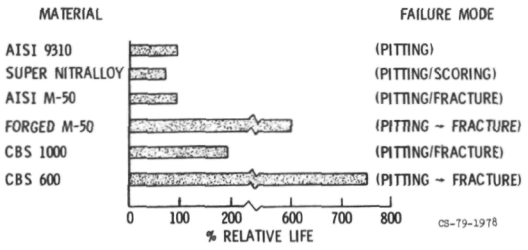
TYPICAL GEAR TOOTH FAILURE MODES



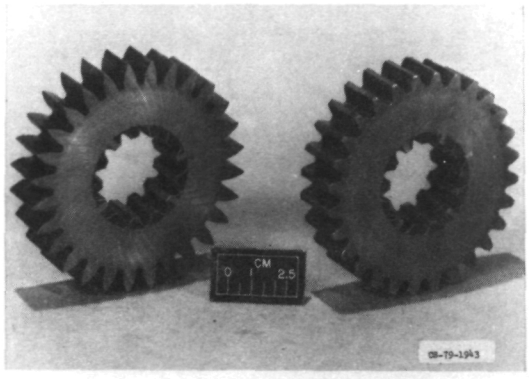
WEIBULL PLOT - GEAR PITTING FATIGUE



NASA GEAR FATIGUE TEST RESULTS

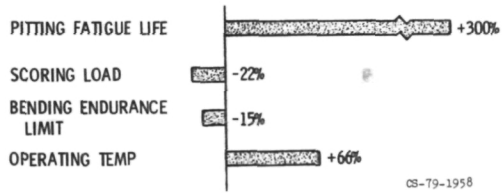


HIGH CONTACT RATIO & STANDARD GEARS

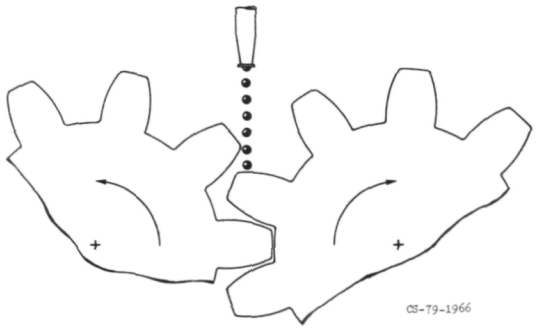


PERFORMANCE COMPARISON

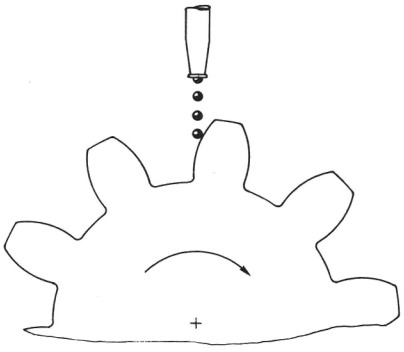
HIGH CONTACT RATIO GEARS VS STANDARD GEARS



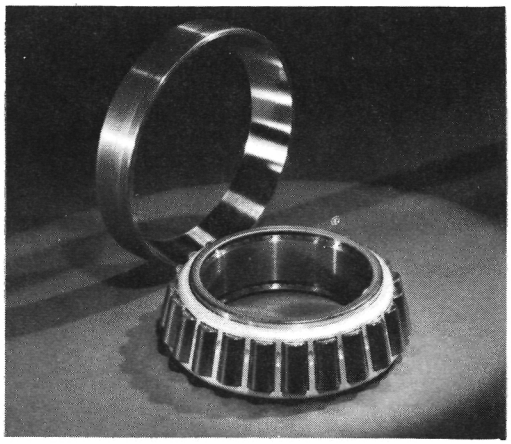
OUT-OF-MESH JET



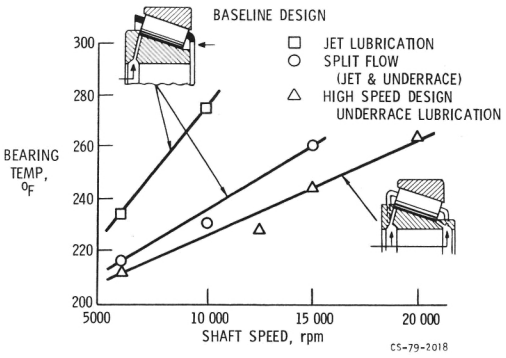
RADIAL JET



C5-79-1960



HIGH SPEED TAPERED ROLLER BEARING



C5-79-2018

SUMMATION

- EXTENDED BEARING LIFE WITH FINER LUBRICANT FILTRATION
- SUCCESSFUL RIG TESTING & SCHEDULED ENGINE TEST OF A SPIRAL GROOVE SELF-ACTING SEAL
- IMPROVED TURBINE ENGINE PERFORMANCE WITH PROMISE OF SIGNIFICANTLY GREATER GAINS THROUGH APPLICATION OF ABRADABLE CERAMIC TURBINE BLADE TIP SEALS
- BETTER CONTROL OF ROTOR VIBRATION WITH AUTOMATED HIGH SPEED BALANCING & ELASTOMER DAMPERS
- EXTENDED GEAR LIFE WITH NEW MATERIALS & HIGH CONTACT RATIO TOOTH FORMS
- MORE EFFECTIVE GEAR LUBRICATION WITH RADIALLY DIRECTED OIL JETS
- IMPROVED DESIGN & LUBRICATION OF HIGH SPEED TAPERED ROLLER BEARINGS FOR TRANSMISSIONS

C5-79-1971

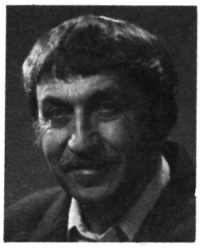
Dg

IX. INSTRUMENTATION TECHNOLOGY

William C. Nieberding, Chairman
David R. Englund, Jr.
George E. Glawe

WILLIAM C. NIEBERDING is Assistant Chief of the Instrumentation Development and Applications Branch, Airbreathing Engines Division. He joined the NASA Lewis staff in 1959 after receiving B.S. and M.S. degrees in physics from John Carroll University. He has specialized in the electronics aspects of measurement systems and is currently concerned with the application of optic and microprocessor technology to measurements.

DAVID R. (BOB) ENGLUND of the Instrumentation Development and Applications Branch, Airbreathing Engines Division, began his career at NASA Lewis in 1954. He holds B.S. (1951) and M.S. (1955) degrees in mechanical engineering from Yale University. He has specialized in measurement system design and application and is currently concerned with pressure and gas analysis instrumentation for turbine engines.



GEORGE E. GLAWE joined the NASA Lewis staff in 1942 while attending Fenn College under a co-op plan. He received a B.S. degree in mechanical engineering in 1951. He has specialized in temperature, pressure, and flow instrumentation. As a member of the Instrumentation Development and Applications Branch, Airbreathing Engines Division, he is working on instrumentation for compressor, combustor, and turbine research.

INSTRUMENTATION TECHNOLOGY

CURRENT NEEDS:

- MAKE MORE MEASUREMENTS UNDER MORE SEVERE CONDITIONS
- MAKE DYNAMIC MEASUREMENTS
- OBTAIN & REDUCE MORE DATA MUCH FASTER

TECHNOLOGY ADVANCES BEING EXPLOITED:

- OPTICS
- MICROELECTRONICS

CS-79-1629

TOPICS TO BE COVERED

- BLADE TIP CLEARANCE MEASUREMENT
- PULSED THERMOCOUPLE
- OPTICAL INSTRUMENTATION FOR FLUTTER
- UNSTEADY PRESS. MEASUREMENT ON BLADES
- DRAG FORCE ANEMOMETER
- LASER ANEMOMETER

CS-79-1627

BLADE TIP CLEARANCE

OBJECTIVE

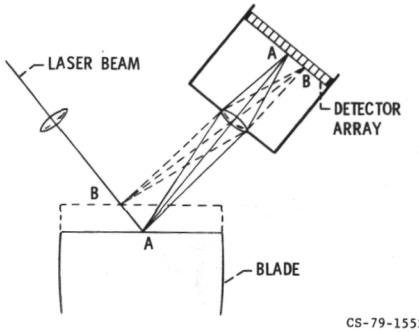
DEVELOP LASER PROBE SYSTEM TO MEASURE INDIVIDUAL BLADE TIP CLEARANCE

PERFORMANCE

RANGE OF MEASUREMENT	5 TO 125 MILS
ACCURACY	2 MILS
RESOLUTION	1 MIL
TEMP	UP TO 1900° F

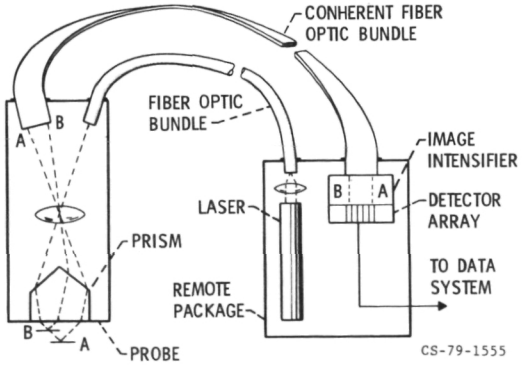
CS-79-1553

OPTICAL TIP CLEARANCE PROBE

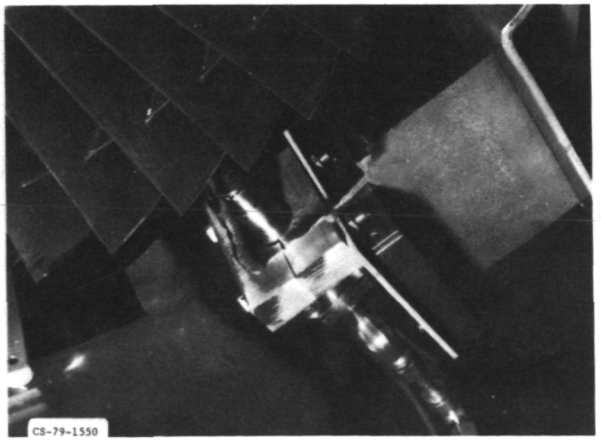


CS-79-1552

OPTICAL TIP CLEARANCE SYSTEM



CS-79-1555



CS-79-1550

TOPICS TO BE COVERED

BLADE TIP CLEARANCE MEASUREMENT

PULSED THERMOCOUPLE

OPTICAL INSTRUMENTATION FOR FLUTTER

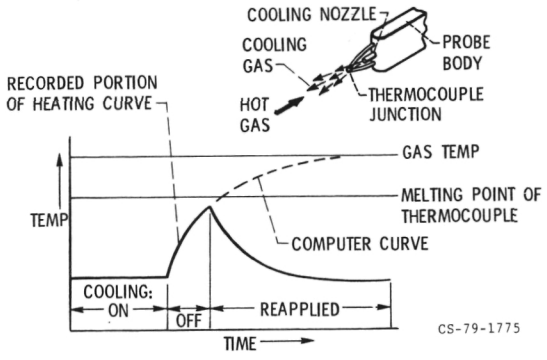
UNSTEADY PRESS. MEASUREMENT ON BLADES

DRAG FORCE ANEMOMETER

LASER ANEMOMETER

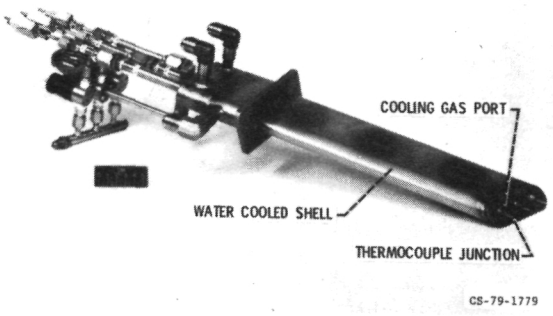
CS-79-1627

PULSED THERMOCOUPLE SYSTEM



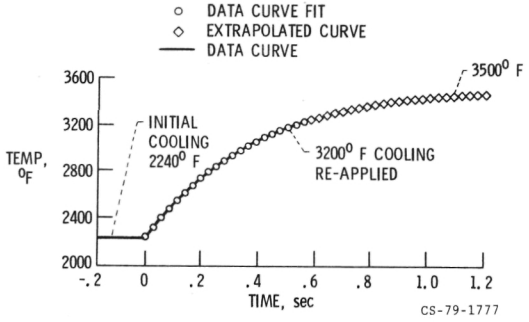
CS-79-1775

THREE ELEMENT PULSED THERMOCOUPLE PROBE



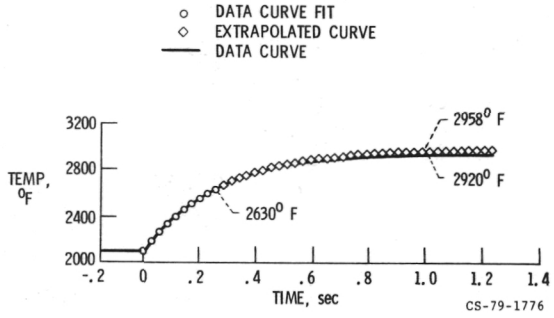
CS-79-1779

PULSED THERMOCOUPLE HIGH TEMPERATURE RUN



CS-79-1777

PULSED THERMOCOUPLE LOW TEMPERATURE RUN



CS-79-1776

TOPICS TO BE COVERED

BLADE TIP CLEARANCE MEASUREMENT

PULSED THERMOCOUPLE

OPTICAL INSTRUMENTATION FOR FLUTTER

UNSTEADY PRESS. MEASUREMENT ON BLADES

DRAG FORCE ANEMOMETER

LASER ANEMOMETER

CS-79-1627

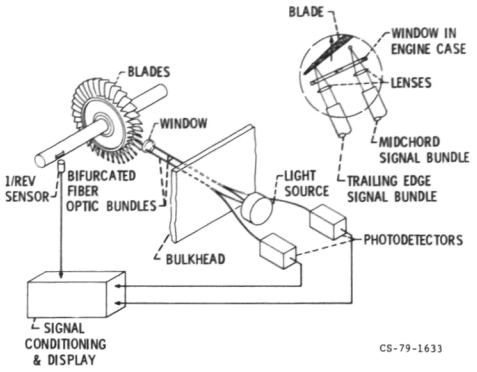
BLADE FLUTTER MEASUREMENT

STRAIN GAGE METHOD:
- PROBLEMS
  - NEVER ENOUGH GAGES
  - SHORT LIFE IN ENGINES

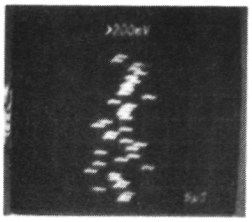
OPTICAL METHOD:
- ADVANTAGES
  - SENSES ALL BLADES
  - NONCONTACTING
  - NONROTATING SENSORS

CS-79-1628

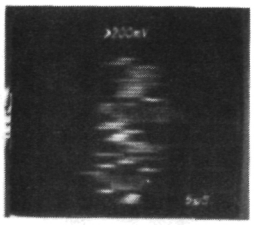
OPTICAL DETECTION OF BLADE VIBRATION AMPLITUDE



CS-79-1633



DISPLAY DURING QUIET RUNNING CONDITION



DISPLAY DURING FLUTTER

CS-79-1634

TOPICS TO BE COVERED

BLADE TIP CLEARANCE MEASUREMENT

PULSED THERMOCOUPLE

OPTICAL INSTRUMENTATION FOR FLUTTER

UNSTEADY PRESS. MEASUREMENT ON BLADES

DRAG FORCE ANEMOMETER

LASER ANEMOMETER

CS-79-1627

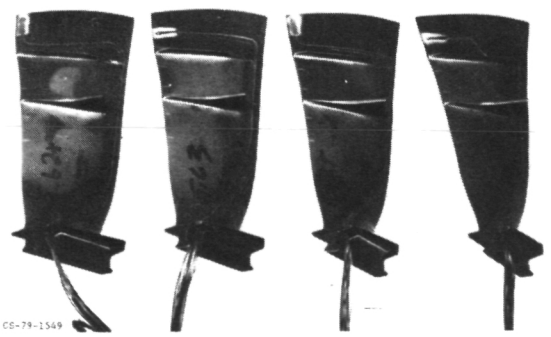
MEASURING UNSTEADY PRESSURE ON ROTATING BLADES

OBJECTIVES

DESIGN TRANSDUCER MOUNTING CONFIGURATIONS

IDENTIFY & QUANTIFY ERROR SOURCES

CS-79-1551



CS-79-1549

MEASURING UNSTEADY PRESSURE ON ROTATING BLADES

OBJECTIVES
- DESIGN TRANSDUCER MOUNTING CONFIGURATIONS
- IDENTIFY & QUANTIFY ERROR SOURCES

ENVIRONMENT
- 90 000 g CENTRIPETAL ACCELERATION
- 70 TO 300^0 F TEMP
- ±1000 με DYNAMIC STRAIN

RESULTS - TYPICAL ERRORS
- ±6% DUE TO SENSITIVITY CHANGE
- ±0.02 psi DUE TO VIBRATION & STRAIN

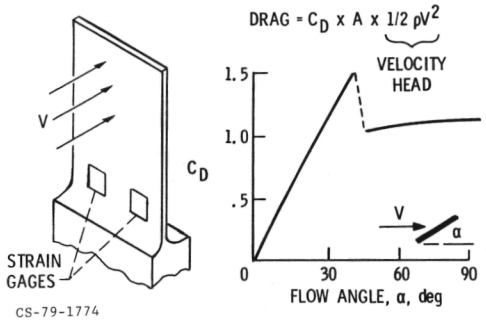
CS-79-1554

TOPICS TO BE COVERED

BLADE TIP CLEARANCE MEASUREMENT
PULSED THERMOCOUPLE
OPTICAL INSTRUMENTATION FOR FLUTTER
UNSTEADY PRESS. MEASUREMENT ON BLADES
DRAG FORCE ANEMOMETER
LASER ANEMOMETER

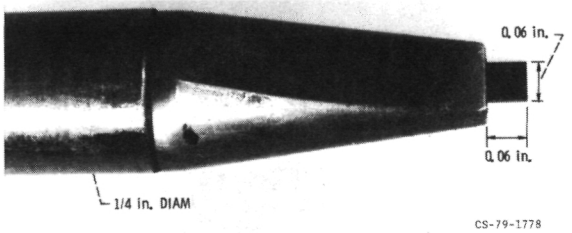
CS-79-1627

DRAG FORCE ANEMOMETER



CS-79-1774

DRAG FORCE ANEMOMETER PROBE



CS-79-1778

DRAG FORCE ANEMOMETER

PERFORMANCE
- LINEAR WITH VELOCITY HEAD UP TO 0.6 M
- MEASURES FLOW REVERSALS
- DYNAMIC FLOW ANGLE OVER ±40 deg
- FREQUENCY RESPONSE (SILICON BEAM) 8 kHz

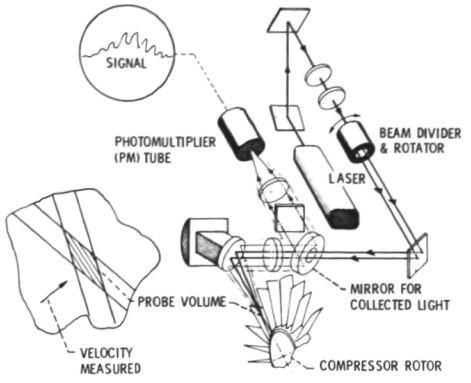
APPLICATIONS
- COMPRESSOR BLADE FLUTTER
- COMPRESSOR DYNAMICS
- DYNAMIC FLOW ANGLE DOWNSTREAM OF TURBINE
- TURBULENCE INTENSITY

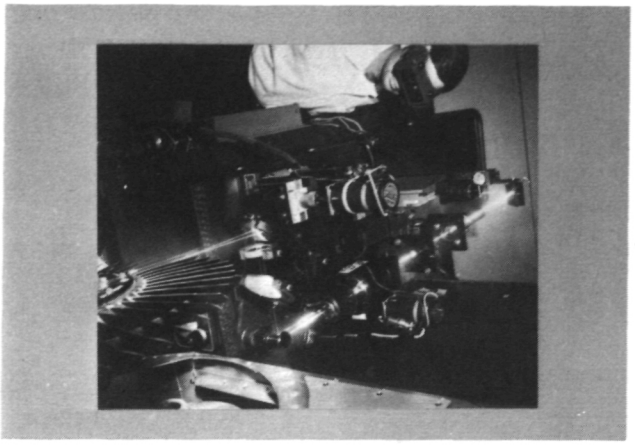
CS-79-1773

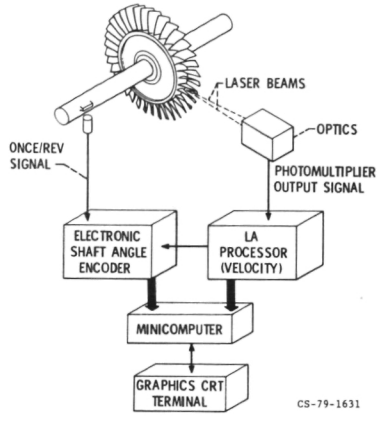
TOPICS TO BE COVERED

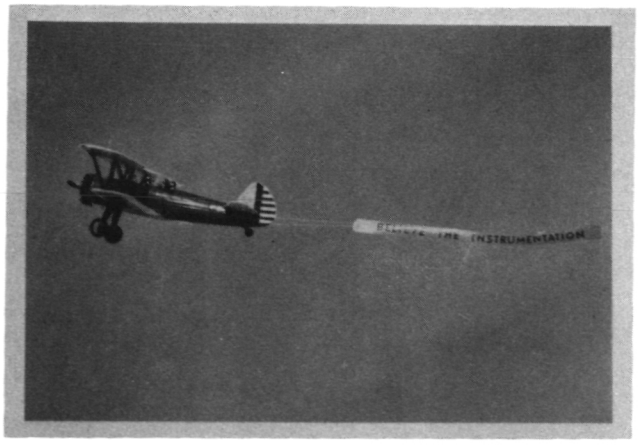
BLADE TIP CLEARANCE MEASUREMENT
PULSED THERMOCOUPLE
OPTICAL INSTRUMENTATION FOR FLUTTER
UNSTEADY PRESS. MEASUREMENT ON BLADES
DRAG FORCE ANEMOMETER
LASER ANEMOMETER

CS-79-1627









TOPICS COVERED

BLADE TIP CLEARANCE MEASUREMENT

PULSED THERMOCOUPLE

OPTICAL INSTRUMENTATION FOR FLUTTER

UNSTEADY PRESS. MEASUREMENT ON BLADES

DRAG FORCE ANEMOMETER

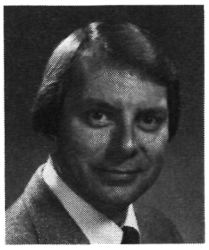
LASER ANEMOMETER

CS-79-1630

D10

X. CONTROL TECHNOLOGY

John R. Szuch



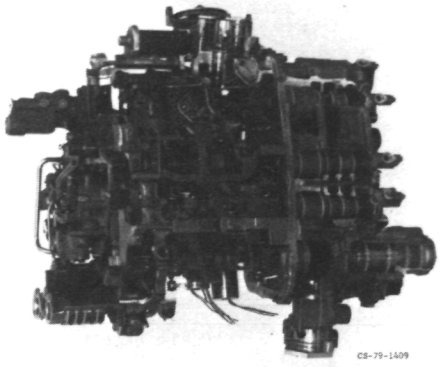
JOHN R. SZUCH is Head of the System Dynamics Section, Wind Tunnel and Flight Division, at NASA Lewis. He joined the Lewis staff in 1962 after attending the Case Institute of Technology, where he obtained a B.S. degree in electrical engineering. He has specialized in mathematical modeling and simulation of rocket and jet engines.

BASIC ENGINE CONTROL FUNCTIONS

STARTING
ACCELERATION/DECELERATION
SPEED GOVERNING
MECHANICAL LIMIT PROTECTION
FUEL METERING/SHUTOFF
VANE/BLEED CONTROL

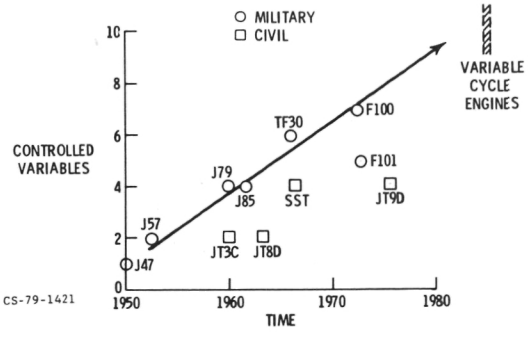
CS-79-1415

CUTAWAY OF F100 HYDROMECHANICAL CONTROL



CS-79-1409

TRENDS IN CONTROL COMPLEXITY



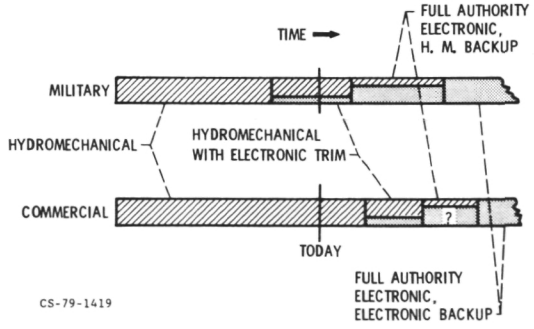
CS-79-1421

DESIRABLE FEATURES OF ADVANCED ENGINE CONTROLS

MULTIVARIABLE CONTROL
THRUST RATING
OVERTEMP LIMITING
SELF-TRIM
CONDITION MONITORING
FAULT TOLERANCE
INTERFACE WITH A/C SYSTEMS

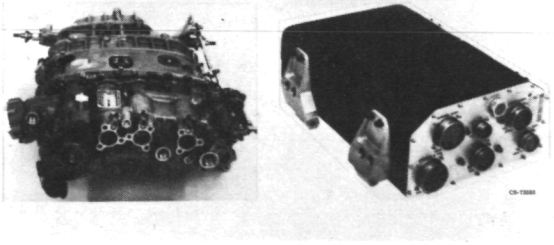
CS-79-1412

EVOLUTION OF ENGINE CONTROLS

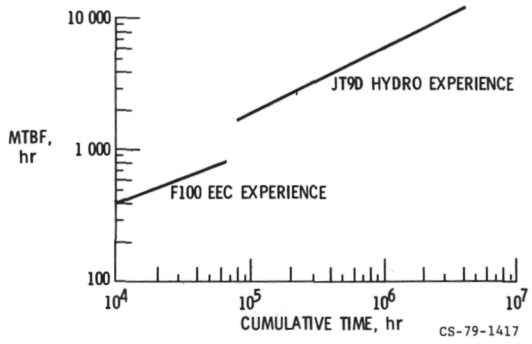


CS-79-1419

HYDROMECHANICAL ENGINE CONTROL WITH ELECTRONIC TRIM-F100



CONTROL SYSTEM RELIABILITY



CS-79-1417

RELIABILITY ENHANCEMENT AREAS

- ELECTRONIC CONTROLLERS
- CONTROL SOFTWARE
- CONTROL INTERFACE COMPONENTS
- CONTROL INTEGRATION

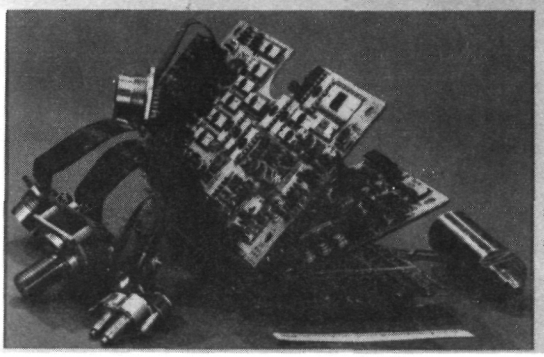
CS-79-1536

NASA-DOD PROPULSION CONTROL PROGRAMS

PROGRAM - SPONSORS	EMPHASIS
ATDE - ARMY QCSEE - NASA FADEC - NAVY	ELECTRONIC CONTROLLERS
MVCS - NASA, AF	CONTROL SOFTWARE
ADV COMPONENTS - NASA	INTERFACE COMPONENTS
IPCS - NASA, AF IPAC - NASA, NAVY, AF	CONTROL INTEGRATION

CS-79-1410

STAGG ELECTRONIC CONTROL CONSTRUCTION



QCSEE OTW ENGINE CONTROL FEATURES

- FULL-AUTHORITY DIGITAL
- THRUST-RATING
- RAPID THRUST RESPONSE
- FICA SOFTWARE
- ENGINE CONDITION MONITORING
- AIRCRAFT COMPUTER INTERFACE

CS-79-1411

FULL AUTHORITY DIGITAL ELECTRONIC CONTROL PROGRAM

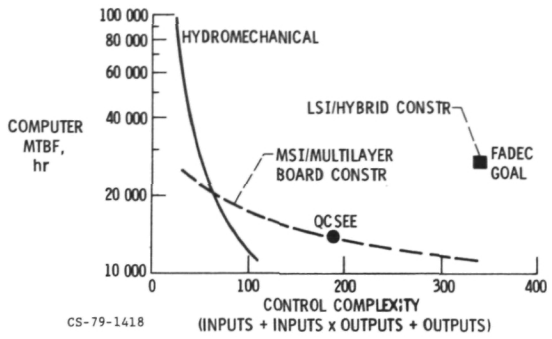
NAVY CONTRACT WITH PRATT & WHITNEY & GE TO DESIGN, FABRICATE, & TEST AN ENGINE MOUNTED DIGITAL CONTROL SYSTEM FOR AN ADVANCED MILITARY ENGINE

FADEC GOALS:

- LIFE CYCLE COST REDUCTION - 30%
- ACQUISITION COST REDUCTION - 25%
- WEIGHT REDUCTION - 25%
- MAINTENANCE TIME REDUCTION - 50%
- MTBF - 2000 hr

CS-79-1416

FADEC COMPUTER RELIABILITY



CS-79-1418

MULTIVARIABLE CONTROL SYNTHESIS PROGRAM

LQR CONTROL THEORY

COMPUTER-AIDED DESIGN

VERIFIED ON HYBRID SIMULATION

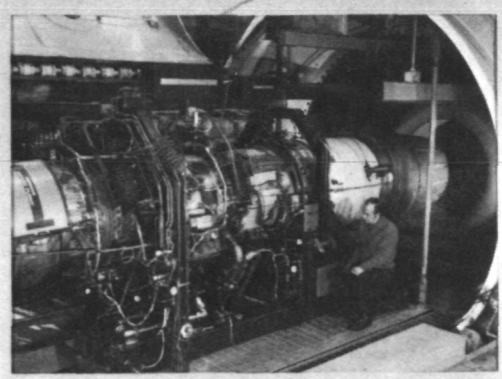
DEMONSTRATED ON F-100 IN ALTITUDE FACILITY

CS-79-1414

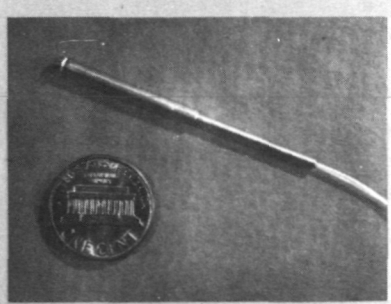
LeRC HYBRID COMPUTING SYSTEM

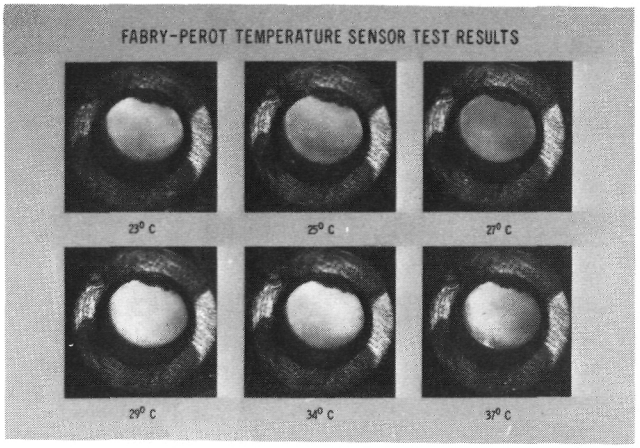
F-100 MULTIVARIABLE CONTROL TESTS

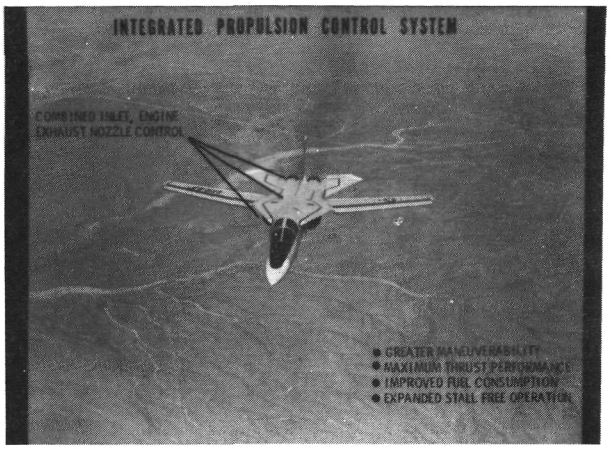
F-100 TURBOFAN IN LeRC ALTITUDE CHAMBER



COMPLETE FIBER-OPTIC FABRY-PEROT TEMPERATURE SENSOR





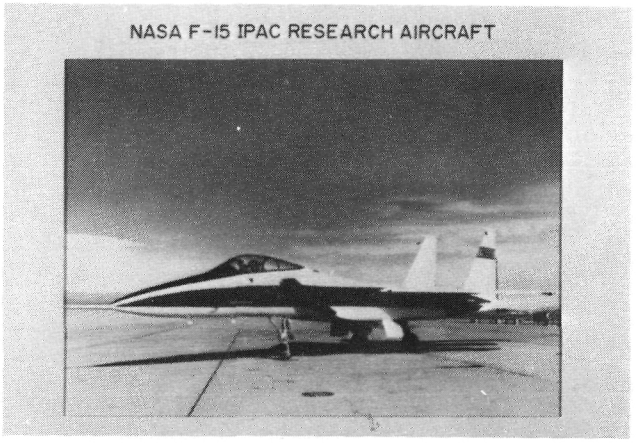


INTEGRATED PROPULSION-AIRFRAME CONTROL PROGRAM

PROVIDE A FLEXIBLE FLIGHT RESEARCH FACILITY FOR DEMONSTRATING:

- INTEGRATED CONTROLS
- AIRCRAFT ENERGY MANAGEMENT
- FADEC
- REAL-TIME ENGINE DIAGNOSTICS
- FAILURE ACCOMODATION
- DATA BUS TECHNOLOGY
- ADVANCED HARDWARE/SOFTWARE

CS-79-1420



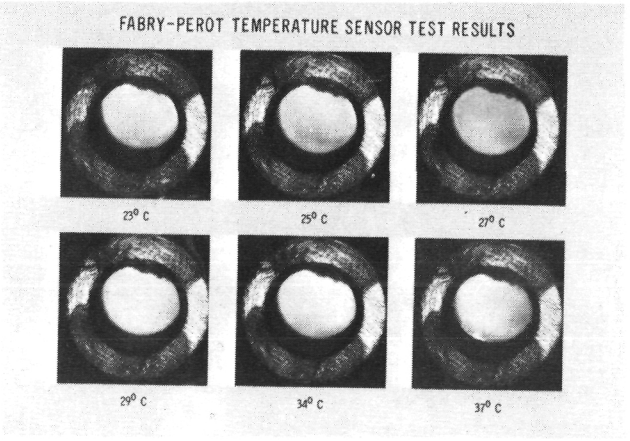
WHAT DOES FUTURE HOLD?

ADVANCES IN COMPUTER TECHNOLOGY WILL ALLOW
- SOPHISTICATED CONTROL ALGORITHMS
- FAULT ACCOMODATION/DIAGNOSTICS
- INTEGRATED CONTROLS

LESS HARDWARE COMPLEXITY

RESULT WILL BE
- BETTER PERFORMANCE
- INCREASED RELIABILITY
- LOWER COST

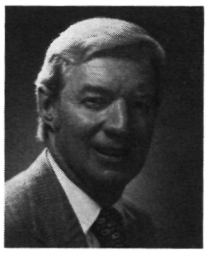
CS-79-1413



D11

XI. SUPERSONIC PROPULSION TECHNOLOGY

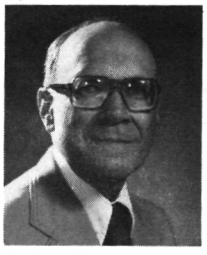
Albert G. Powers, Chairman
Robert E. Coltrin
Leonard E. Stitt
Richard J. Weber
John B. Whitlow, Jr.



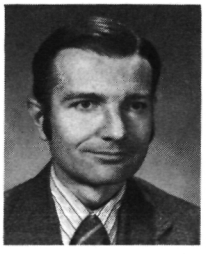
ALBERT G. POWERS joined the NASA Lewis staff in 1955. A native of Cleveland, Ohio, he attended John Carroll University, where he received a B.S. degree in physics in 1955 and an M.S. degree in physics in 1963. He was a supervisor in the system dynamics and control area before joining the Refan Project Office in 1972 and the Variable Cycle Engine Project Office, V/STOL and Noise Division, as manager, in 1976.

ROBERT E. COLTRIN was awarded a B.S. degree in electrical engineering by Cleveland State University in 1962 and an M.S. degree in electrical engineering by the University of Toledo in 1967. Since coming to NASA Lewis in 1962, he has done research on control systems, electric power systems, and internal aerodynamics. Since 1966 he has been engaged in wind tunnel investigations of supersonic inlets and their interactions with turbine engines.

LEONARD E. STITT, currently with the Variable Cycle Engine Project Office, V/STOL and Noise Division, began his NASA Lewis career in 1952. A native of Pittsburgh, Pennsylvania, he attended the University of Notre Dame, where he received a B.S. degree in aeronautical engineering in 1948 and an M.S. degree in 1952. He has specialized in propulsion aerodynamics.



RICHARD J. WEBER is Chief of the Mission Analysis Branch, V/STOL and Noise Division, at NASA Lewis. He joined the Lewis staff in 1951 after obtaining B.S. and M.S. degrees in mechanical engineering from Yale University. His work involves analyzing advanced airbreathing propulsion systems and their suitability for various future aircraft and identifying technology needs.



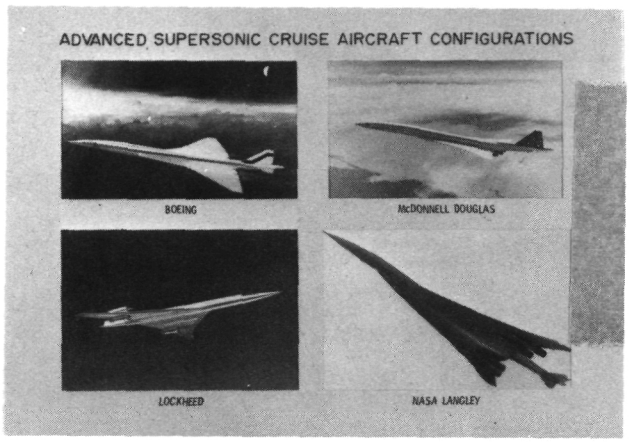
JOHN B. WHITLOW became a member of the NASA Lewis staff in 1962. A native of Lexington, Kentucky, he received B.S. and M.S. degrees in mechanical engineering from the University of Kentucky. Before joining the Variable Cycle Engine Project Office, V/STOL and Noise Division, in 1976, his work at Lewis was in engine-cycle and airplane-mission analysis.

SUPERSONIC PROPULSION

TECHNOLOGY

PANEL

CS-79-1651

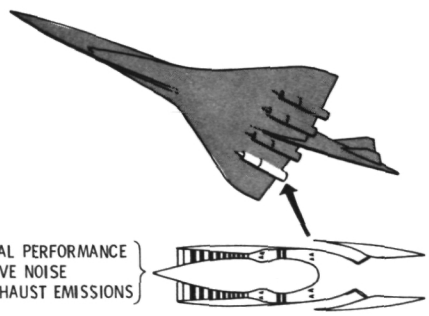


SUPERSONIC PROPULSION TECHNOLOGY

INTRODUCTION	ALBERT G. POWERS
PROPULSION OPTIMIZATION STUDIES	RICHARD J. WEBER
P & WA VARIABLE STREAM CONTROL ENGINE	LEONARD E. STITT
GE DOUBLE BYPASS ENGINE	JOHN B. WHITLOW, JR
SUPERSONIC CRUISE INLETS	ROBERT E. COLTRIN
CONCLUDING REMARKS	ALBERT G. POWERS

CS-79-1653

1971 PROPULSION STATUS



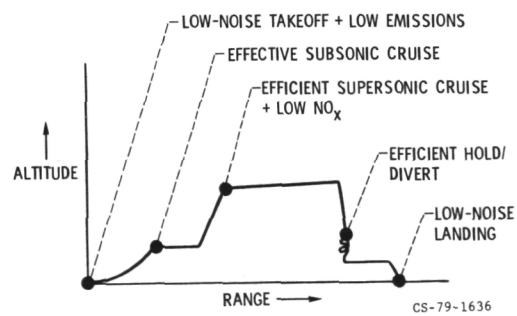
- MARGINAL PERFORMANCE
- EXCESSIVE NOISE
- HIGH EXHAUST EMISSIONS

CS-79-1639

GE-4 AFTERBURNING TURBOJET

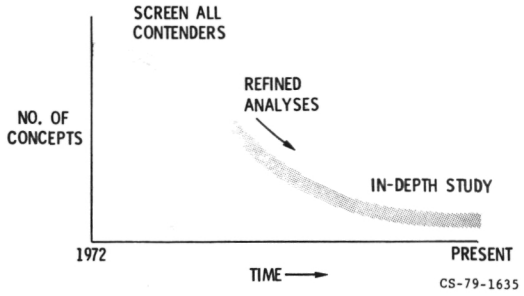
PROPULSION PROGRAM

TYPICAL SUPERSONIC TRANSPORT

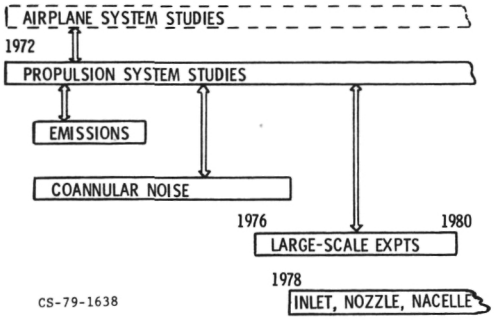


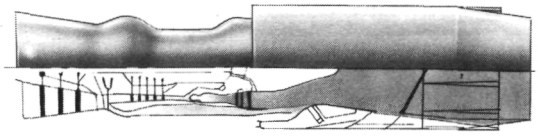
CS-79-1636

EVOLUTION OF ENGINE STUDIES

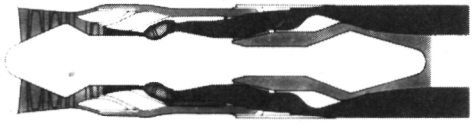


PROPULSION PROGRAM

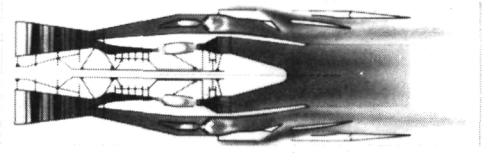




LOW BYPASS ENGINE (LBE)



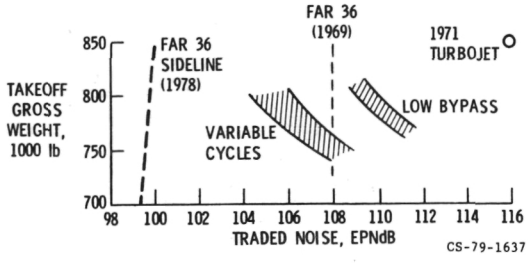
DOUBLE BYPASS ENGINE (DBE)



VARIABLE STREAM CONTROL ENGINE (VSCE)

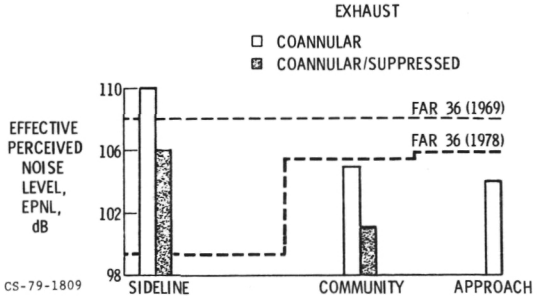
COMPARISON OF ENGINES

M = 2.4; ALL SUPERSONIC CRUISE
292 PASSENGERS
RANGE, 4500 n mi



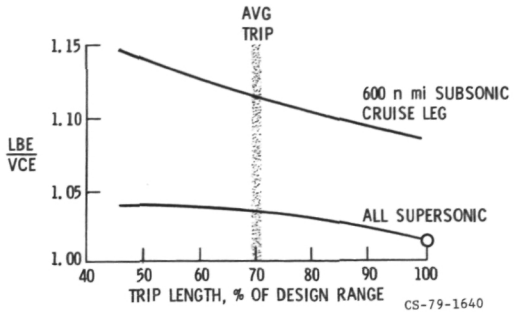
AIRCRAFT NOISE LEVELS

G.E. DOUBLE BYPASS ENGINE



RELATIVE DIRECT OPERATING COST

P & WA ENGINES

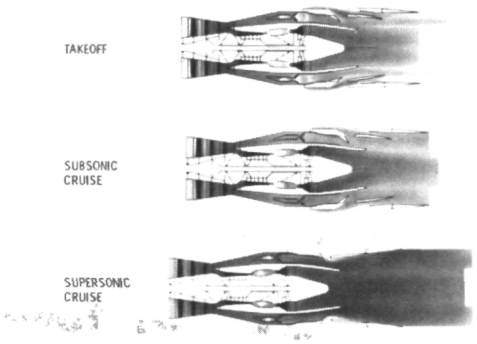


SUPERSONIC PROPULSION TECHNOLOGY

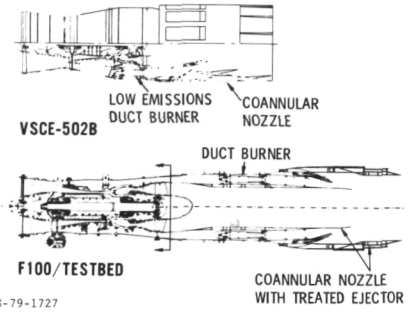
INTRODUCTION	ALBERT G. POWERS
PROPULSION OPTIMIZATION STUDIES	RICHARD J. WEBER
➧ P & WA VARIABLE STREAM CONTROL ENGINE	LEONARD E. STITT
➧ GE DOUBLE BYPASS ENGINE	JOHN B. WHITLOW, JR
SUPERSONIC CRUISE INLETS	ROBERT E. COLTRIN
CONCLUDING REMARKS	ALBERT G. POWERS

CS-79-1655

PRATT AND WHITNEY AIRCRAFT VARIABLE STREAM CONTROL ENGINE

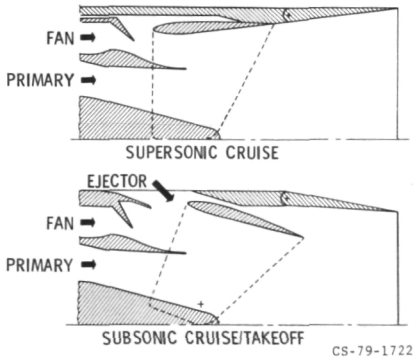


COMPARISON OF VSCE-502B AND TESTBED CONFIGURATION



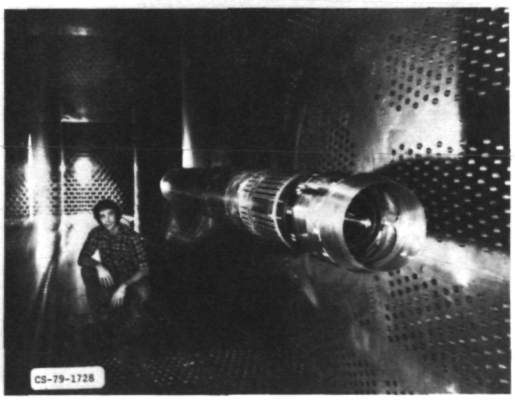
CS-79-1727

VSCE-502B EJECTOR NOZZLE

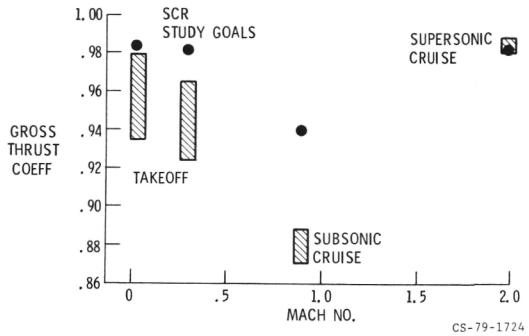


CS-79-1722

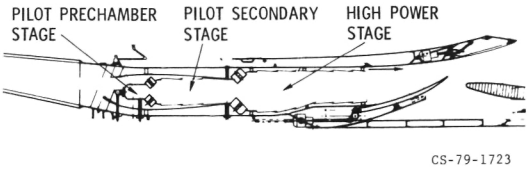
VSCE-502B NOZZLE IN 8'X6' SUPERSONIC WIND TUNNEL



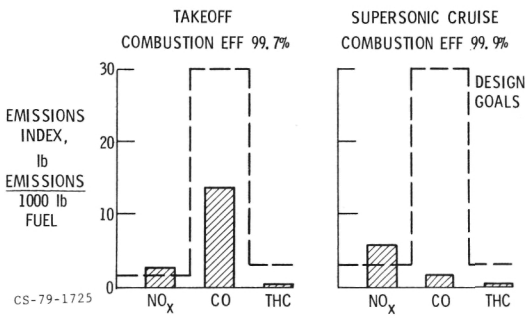
VSCE-502B NOZZLE THRUST PERFORMANCE



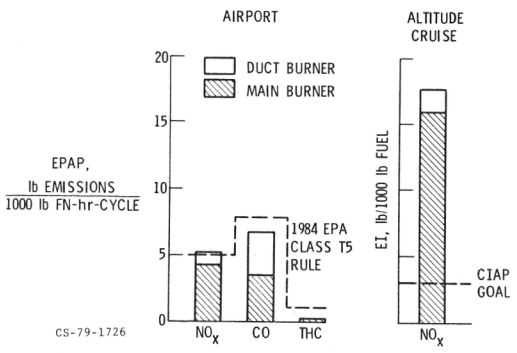
THREE-STAGE VORBIX DUCT BURNER



MEASURED DUCT BURNER EMISSIONS



VSCE-502B EXHAUST EMISSIONS ESTIMATES



THREE STAGE VORBIX DUCT BURNER TEST RESULTS

SOFT LIGHT DEMONSTRATED AT FUEL-AIR RATIO < 0.002
- NO SIGNIFICANT PRESS. PULSE

NO ACOUSTIC INSTABILITY

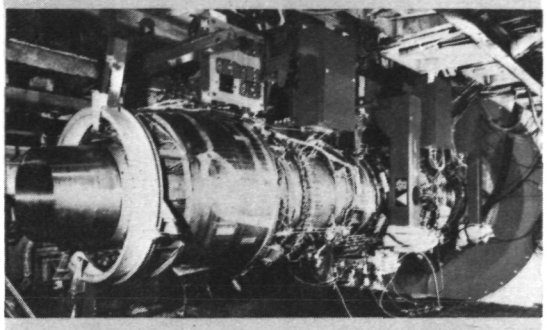
STAGE DURABILITY ESTABLISHED
- TOTAL STAGE 1 TIME: 22 hr
- TOTAL STAGE 2 TIME: 15 hr
- TOTAL STAGE 3 TIME: 9 hr

MEASURED
- LOW EMISSIONS
- COMBUSTION EFF > 99.5%
- THRUST EFF > 97%

CS-79-2168

VSCE/FIOO COMPONENT TESTBED WITH DUCT BURNER OPERATING

VSCE/F100 COMPONENT TESTBED
INSTALLED IN X-16 STAND



VSCE/F100 COMPONENT TEST PROGRAM
PLANS THROUGH 1980

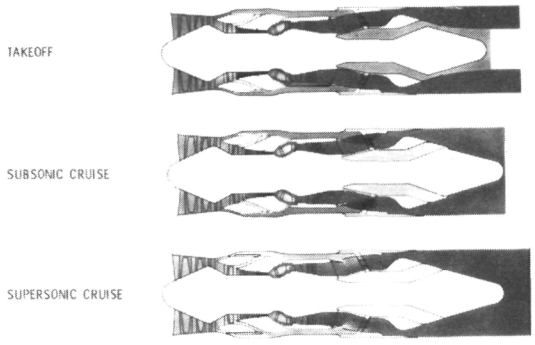
COANNULAR NOZZLE AERO PERFORMANCE IMPROVEMENT STUDY

EMISSIONS TEST OF IMPROVED DUCT BURNER
- SEGMENT RIG
- TESTBED ENGINE

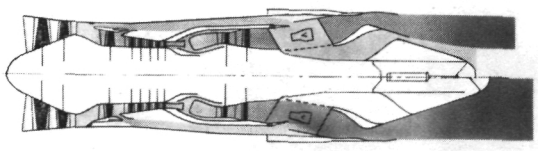
AERO/ACOUSTIC TESTS
- COANNULAR NOZZLE WITH TREATED EJECTOR
- DUCT BURNER COMBUSTION NOISE

CS-79-1721

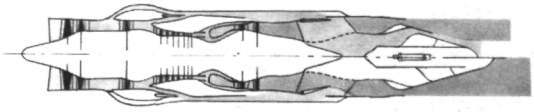
DOUBLE BYPASS ENGINE
GENERAL ELECTRIC CO.



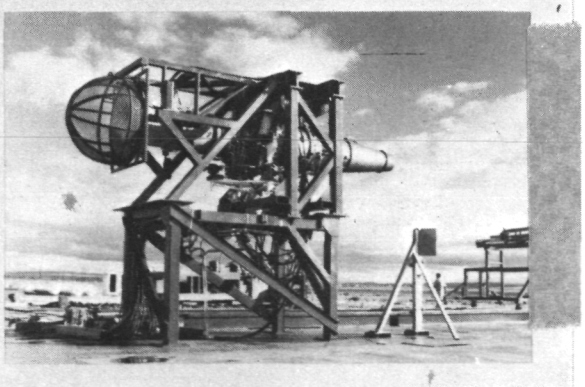
DOUBLE BYPASS ENGINE



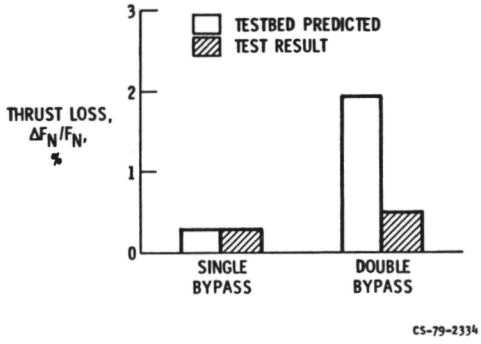
YJ101/EARLY ACOUSTIC
TESTBED ENGINE



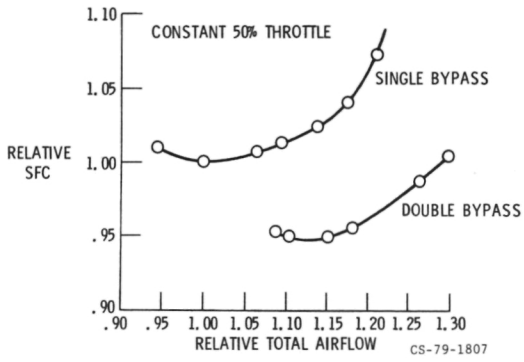
CALIBRATION NOISE TEST OF GE ENGINE



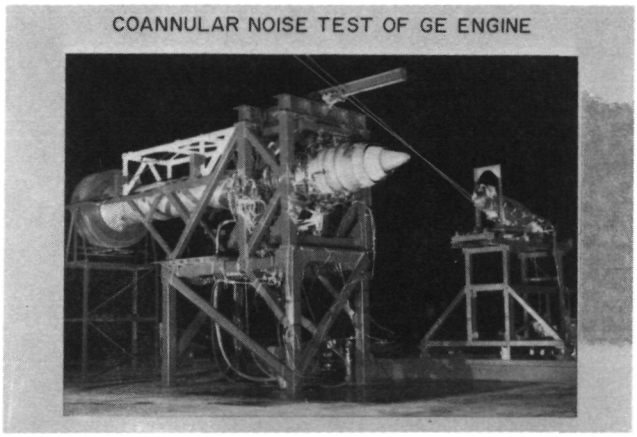
BYPASS SYSTEM LOSS COMPARISON



TESTED ENGINE PERFORMANCE DATA

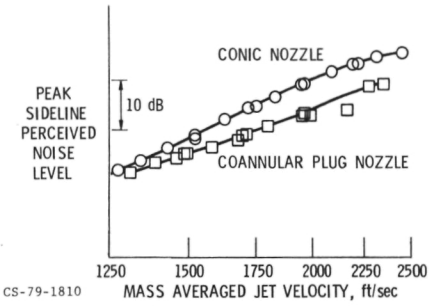


COANNULAR NOISE TEST OF GE ENGINE



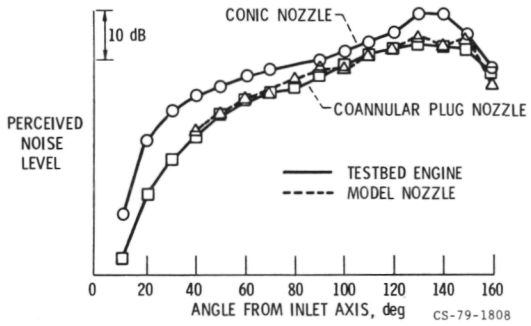
ACOUSTIC TEST DATA

SCALED TO FULL SIZE & 2400 ft SIDELINE

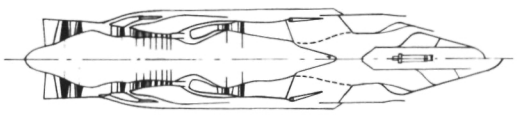


NOISE DIRECTIVITY

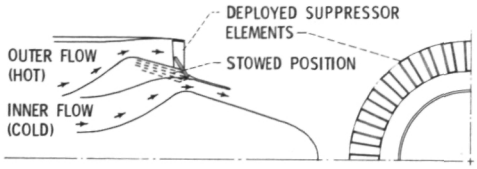
SCALED TO FULL SIZE & 2400 ft SIDELINE; $\bar{V}_J$ = 1950 ft/sec



YJ101/CORE-DRIVEN TESTBED ENGINE



COANNULAR NOZZLE WITH SIMPLE SHALLOW CHUTE SUPPRESSOR



CS-79-1806

SUMMARY

ACCOMPLISHMENTS

- COANNULAR JET NOISE REDUCTION OF ~6 PNdB
- DOUBLE BYPASS AIRFLOW EXTENSION ADVANTAGES AT PART THROTTLE
- SMOOTH TRANSITIONING BETWEEN SINGLE & DOUBLE BYPASS OPERATION
- LOW BYPASS SYSTEM LOSSES

FUTURE PLANS

- UNIQUE CORE-DRIVEN FAN SYSTEM
- SIMPLE OUTER STREAM CHUTED SUPPRESSOR

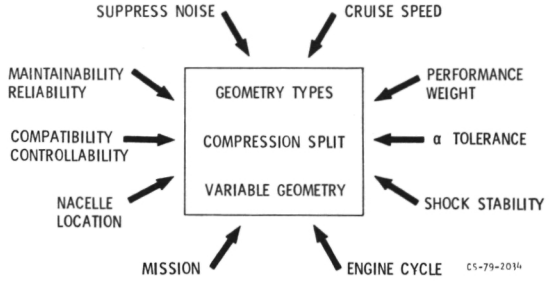
CS-79-1805

SUPERSONIC PROPULSION TECHNOLOGY

INTRODUCTION	ALBERT G. POWERS
PROPULSION OPTIMIZATION STUDIES	RICHARD J. WEBER
P & WA VARIABLE STREAM CONTROL ENGINE	LEONARD E. STITT
GE DOUBLE BYPASS ENGINE	JOHN B. WHITLOW, JR
▶ SUPERSONIC CRUISE INLETS	ROBERT E. COLTRIN
CONCLUDING REMARKS	ALBERT G. POWERS

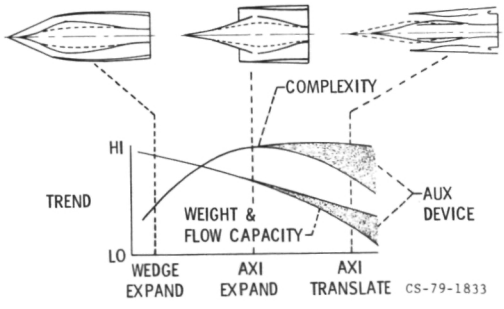
CS-79-1652

INLET DESIGN FACTORS



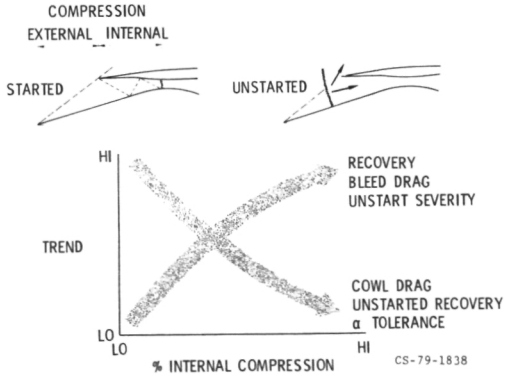
CS-79-2034

INLET GEOMETRY TYPES



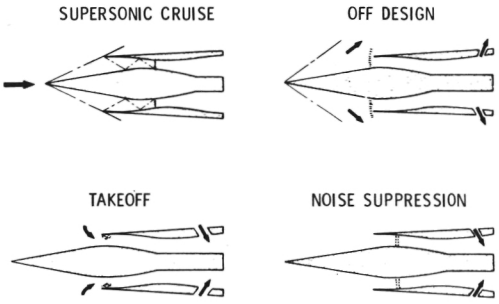
CS-79-1833

EFFECT OF INLET INTERNAL COMPRESSION



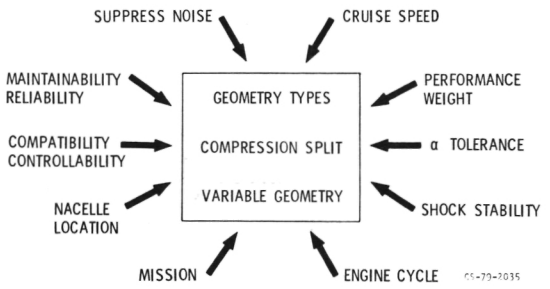
CS-79-1838

INLET VARIABLE GEOMETRY



CS-79-1835

INLET DESIGN FACTORS



CS-79-2035

EXPANDING AXI INLET EVALUATION

BOEING DOUGLAS LOCKHEED

DESIGN
ESTIMATE PERFORMANCE
DEFINE UNIQUE FEATURES
COMPARE
TECH RECOMMENDATIONS

CS-79-1831

EXPANDING INLET EVALUATION

GENERAL AGREEMENT

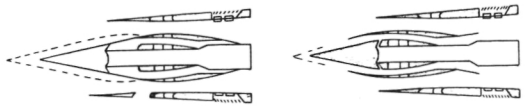
LESS BLEED
GREATER α TOLERANCE
MILDER UNSTART
LARGER AIRFLOW
LESS COMPLEX CENTERBODY BLEED
COMPLEX CENTERBODY LEAF SEALS
POSSIBLE SEAL LEAKAGE PROBLEMS
NOISE SUPPRESSION TESTING REQUIRED

CS-79-1830

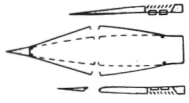
DOUGLAS INLET GEOMETRIES

CRUISE MACH = 2.2

TRANSLATING



EXPANDING



CS-79-1836

DOUGLAS EXPANDING INLET EVALUATION

3.3% MORE RANGE
- 27% LESS WEIGHT
- BETTER SUPERSONIC CRUISE SFC
- MORE CLIMB THRUST

FEWER OPERATING MECHANISMS

LESS AREA FOR ACOUSTIC TREATMENT

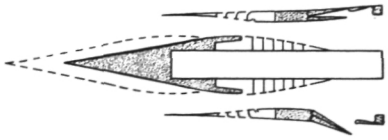
VALID VCE CONCEPT
- VERIFICATION REQUIRED
- SHOULD PURSUE BETTER VCE FLOW MATCH

CS-79-1827

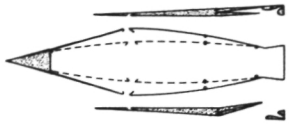
BOEING INLET GEOMETRIES

CRUISE MACH = 2.4

TRANSLATING



EXPANDING



CS-79-1837

BOEING EXPANDING INLET EVALUATION

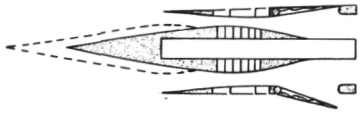
- 1.7% LESS RANGE
  - 42% MORE WEIGHT
- BETTER SFC
  - SUPERSONIC CRUISE
  - CLIMB
- GREATER BENEFITS AT LOWER CRUISE SPEED
- VALID VCE CONCEPT
  - VERIFICATION REQUIRED

CS-79-1832

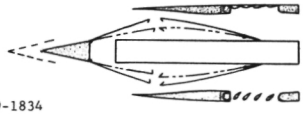
LOCKHEED INLET GEOMETRIES

CRUISE MACH = 2.55

TRANSLATING



EXPANDING



CS-79-1834

LOCKHEED EXPANDING INLET EVALUATION

- 3% MORE RANGE
  - BETTER SUPERSONIC CRUISE SFC
  - BETTER CLIMB ENGINE FLOW MATCH
- BETTER TAKEOFF RECOVERY
- NO COWL BLEED
  - ALLOWS ACOUSTIC TREATMENT
  - PROVIDES AUX INLET OPTIONS
- 21% MORE WEIGHT
- PREFERRED
  - CONTINUE CONCEPT SCREENING

CS-79-1829

EXPANDING INLET EVALUATION SUMMARY

CONCLUSIONS
- RANGE COMPARABLE
- OTHER FACTORS IMPORTANT
- ADDS VCE FLOW MATCH OPTION

RECOMMENDATIONS
- EXPERIMENTAL VERIFICATION REQUIRED
- CONCEPT SCREENING SHOULD CONTINUE
- EARLY NOISE SUPPRESSION TESTING REQUIRED

CS-79-1828

SUPERSONIC PROPULSION TECHNOLOGY

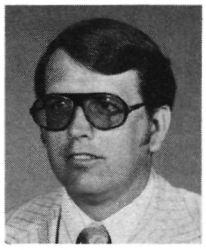
INTRODUCTION	ALBERT G. POWERS
PROPULSION OPTIMIZATION STUDIES	RICHARD J. WEBER
P & WA VARIABLE STREAM CONTROL ENGINE	LEONARD E. STITT
GE DOUBLE BYPASS ENGINE	JOHN B. WHITLOW, JR
SUPERSONIC CRUISE INLETS	ROBERT E. COLTRIN
▶ CONCLUDING REMARKS	ALBERT G. POWERS

CS-79-1654

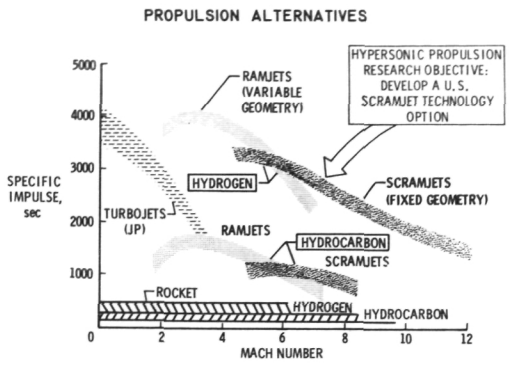
D12

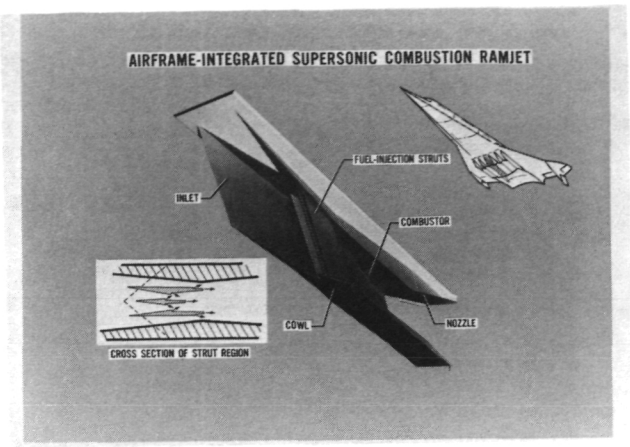
XII. HYPERSONIC PROPULSION

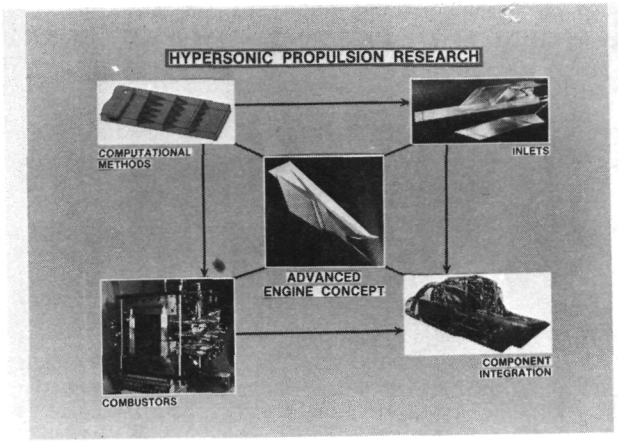
H. Lee Beach, Jr.



H. LEE BEACH, JR., Leader of the Performance Analysis Group, in the NASA Langley Hypersonic Propulsion Branch, has been involved with scramjet-related research since joining NASA 9 years ago. From 1970 to 1975, he conducted fundamental experimental and analytical research in supersonic combustion processes and directed such efforts from 1975 to 1977 as Head of the Combustion Section. During this time, he was responsible for building a computational fluid mechanics capability for scramjet internal flows. In addition to continued involvement with computational work, his current responsibilities include engine design and subscale engine testing. He has received B.S., M.S., and Ph.D. degrees from North Carolina State University.







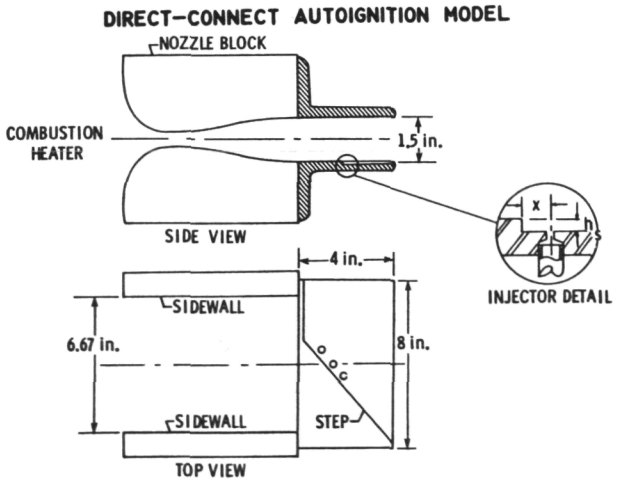
COMPONENT RESEARCH STATUS

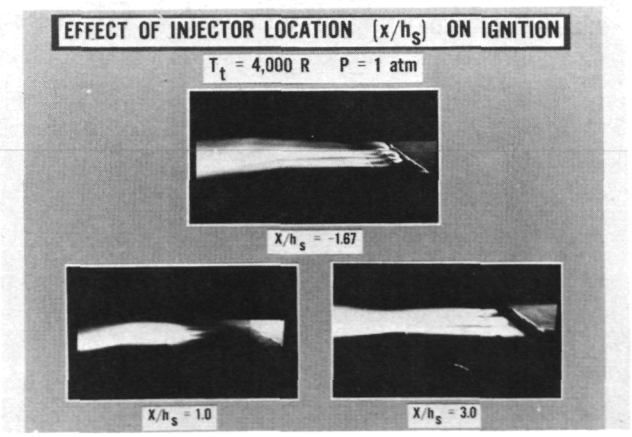
INLETS

- BASELINE 3-STRUT INLET AERODYNAMIC PERFORMANCE FIRMLY ESTABLISHED
  - EVOLVED FROM TESTS AND ANALYSIS OF FOUR GENERATIONS OF INLET DESIGN
  - OPERATING CHARACTERISTICS EXCELLENT - DOCUMENTED FOR MACH 3 - 8 RANGE
- PRESENT ACTIVITY DIRECTED TOWARD COMBUSTOR-INLET INTERACTIONS

COMBUSTORS

- MIXING PERFORMANCE OF BASELINE CONCEPT WELL ESTABLISHED
  - DIRECT CONNECT TESTS OF MANY CONFIGURATIONS
  - MODULE COMBUSTOR DESIGN LENGTH ADEQUATE FOR 95% MIXING
  - DUAL MODE INJECTION SUCCESSFULLY DEMONSTRATED
- PRESENT ACTIVITY DIRECTED TOWARD IGNITION/FLAMEHOLDING BEHAVIOR AND FLOW DIAGNOSTICS

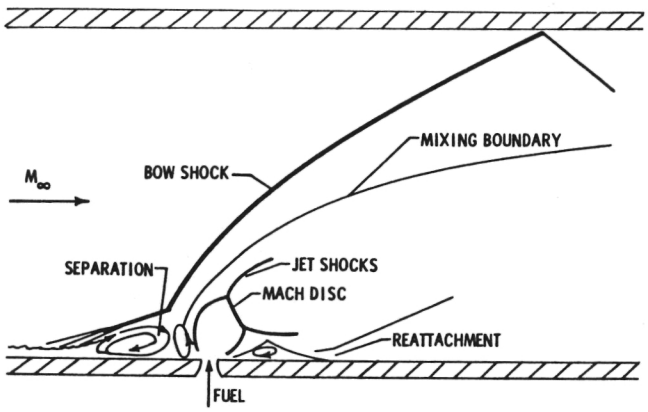




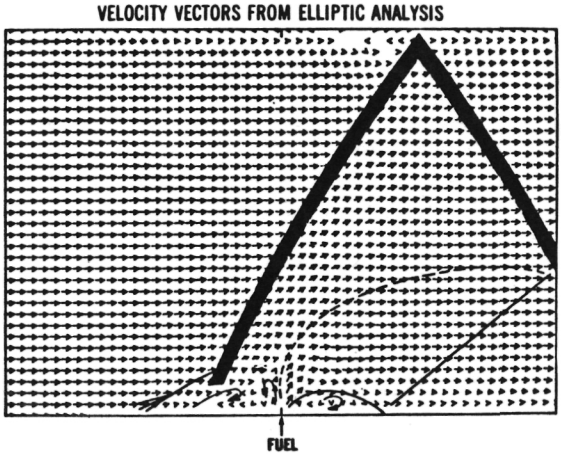
SCRAMJET ANALYSIS PROBLEM STATEMENT

- THEORETICAL EFFORT FOR SCRAMJETS AIMED AT PROVIDING TOOLS FOR ENGINE DESIGN AND ANALYSIS (PERFORMANCE PARAMETERS, HEAT RELEASE CONTROL, ETC.)
- ONE OF THE MOST CHALLENGING PROBLEMS FOR ANALYSIS
  - THREE-DIMENSIONAL FLOWS
  - MIXING
  - REACTION
  - TURBULENCE
  - SEPARATION
  - RE-CIRCULATION
  - SHOCKS
- UNIQUE OPPORTUNITY FOR DETAILED COMBUSTOR ANALYSIS
  - SINGLE PHASE FLOW
  - H_2/AIR CHEMISTRY
- CURRENT FOCUS IS ON COMBUSTORS
  - OPERATIONAL CODES (PARABOLIC) FOR COMBUSTOR FARFIELD CALCULATIONS
  - CODES FOR SEPARATION, RECIRCULATION (ELLIPTIC) UNDER DEVELOPMENT

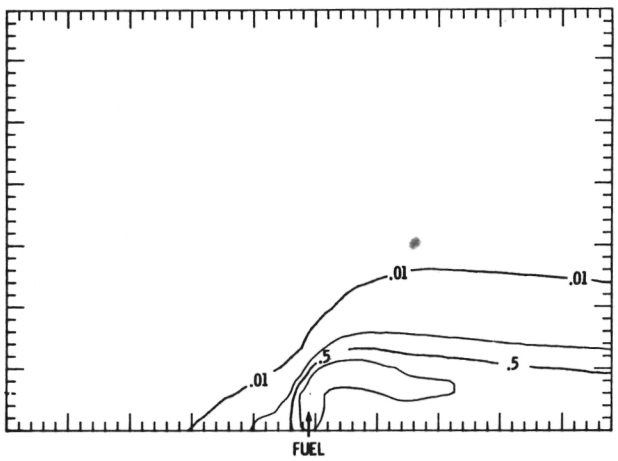
FUEL INJECTOR FLOW FIELD SCHEMATIC



VELOCITY VECTORS FROM ELLIPTIC ANALYSIS

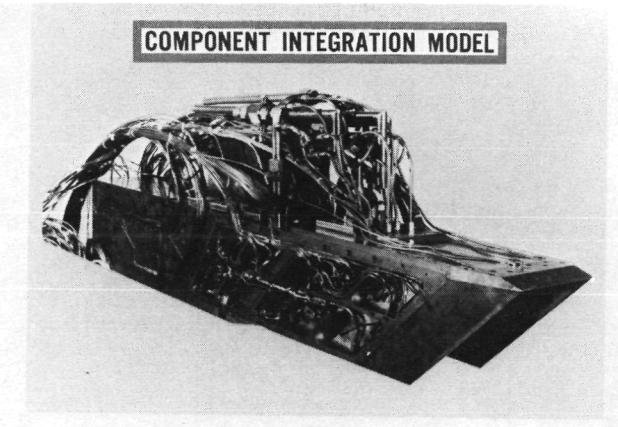


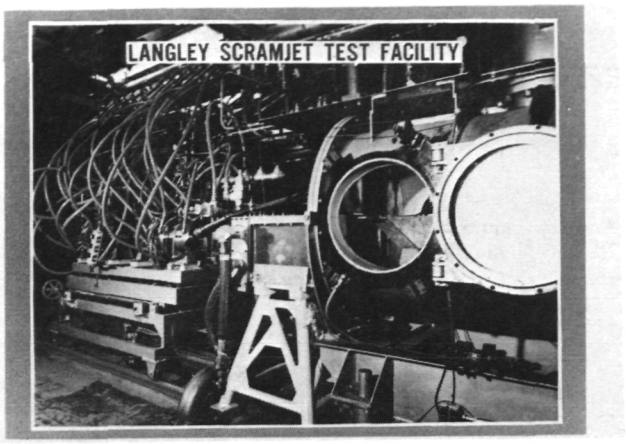
FUEL MASS CONTOURS FROM ELLIPTIC ANALYSIS



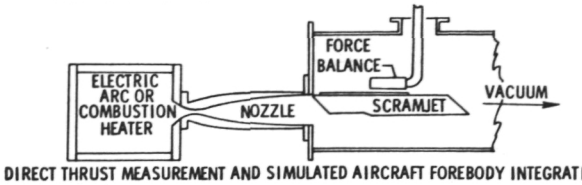
PRELIMINARY SCRAMJET COMPONENT INTEGRATION TESTS

- FIRST ENGINE TESTS OF AIRFRAME-INTEGRATED SCRAMJET CONCEPT
- TEST PURPOSE IS RESEARCH - NOT PERFORMANCE DEMONSTRATION
  - MACH 4: 70 TESTS, 12 MINUTES TEST TIME
  - MACH 7: 100 TESTS, 25 MINUTES TEST TIME
- TESTS AT MACH 4 AND 7 ARE NECESSARY
  - REPRESENTATIVE OF ENGINE OPERATION OVER A WIDE MACH NUMBER RANGE
  - DIFFERENT FUEL INJECTION MODES, SPILLAGE, SUSCEPTIBILITY TO INLET/COMBUSTOR INTERACTION, IGNITION/FLAMEHOLDING CHARACTERISTICS

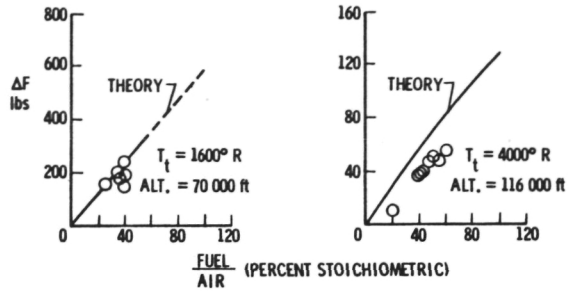




PRELIMINARY SCRAMJET ENGINE PERFORMANCE



DIRECT THRUST MEASUREMENT AND SIMULATED AIRCRAFT FOREBODY INTEGRATION



SUMMARY

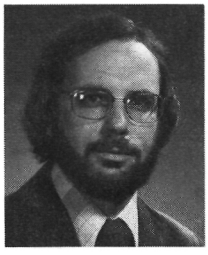
- SIGNIFICANT PROGRESS HAS BEEN MADE TOWARD THE GOAL OF DEVELOPING AN AIRFRAME-INTEGRATED SCRAMJET
  - DEVELOPED FIXED-GEOMETRY INLET FOR MACH 4 - 10
  - DEVELOPED COMBUSTOR/FUEL INJECTORS USING PERPENDICULAR AND PARALLEL INJECTION FOR HEAT RELEASE CONTROL
  - CONDUCTED INITIAL RESEARCH TESTS ON SUBSCALE ENGINES AT MACH 4, 7
  - DEVELOPING ANALYSES WHICH ARE BEGINNING TO IMPACT ENGINE DESIGN
- MANY CHALLENGES REMAIN
  - OPERATION AT HIGH Φ
  - ELIMINATION OF INLET/COMBUSTOR INTERACTIONS
  - OPTIMIZATION OF AEROTHERMODYNAMIC DESIGN
  - DEVELOPMENT OF FLIGHT-WEIGHT STRUCTURE
  - DEMONSTRATION OF ENGINE TECHNOLOGY ON GROUND AND IN FLIGHT

D/3

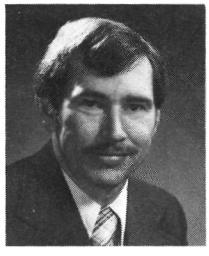
XIII. VERTICAL TAKEOFF AND LANDING (VTOL) PROPULSION TECHNOLOGY

Carl C. Ciepluch, Chairman
John M. Abbott
Royce D. Moore
James F. Sellers

CARL C. CIEPLUCH is Chief of the V/STOL and Rotorcraft Propulsion Office, V/STOL and Noise Division, at NASA Lewis. Joining Lewis in 1952 shortly after graduating from Marquette University with a B.S. degree in mechanical engineering, he has worked in the general area of aeronautical and rocket propulsion.



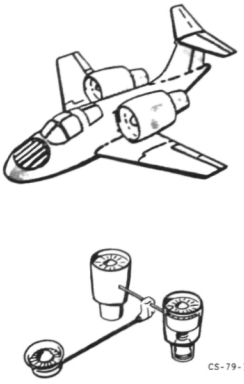
JOHN M. ABBOTT became a member of the NASA Lewis staff in 1970. He was awarded a B.S. degree in aerospace engineering by the University of Michigan in 1970 and has done graduate study at the University of Toledo. At Lewis, he has specialized in subsonic inlet aerodynamics and acoustics and is currently working on inlets for V/STOL aircraft as a member of the Aerodynamic Section, Wind Tunnel and Flight Division.



ROYCE D. MOORE, a native of Mangum, Oklahoma, received a B.S. degree in physics and mathematics from Southwestern Oklahoma State University in 1963. He then joined the NASA Lewis staff and is currently working on fan and compressor research as a member of the Small Compressor Section, Fluid System Components Division.

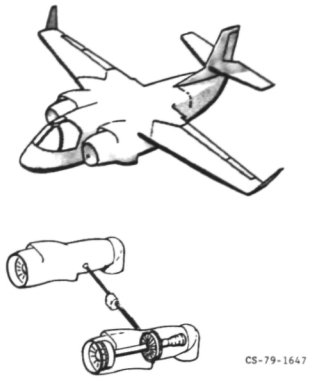
JAMES F. SELLERS is a member of the Propulsion Systems Control Section, Wind Tunnel and Flight Division. He came to NASA Lewis in 1970 after receiving a B.S. degree in aeronautical engineering from Purdue University. In 1978, he received an M.S. degree in electrical engineering from the University of Toledo. His current responsibilties include research on advanced digital control components and VTOL propulsion controls.

REPRESENTATIVE TILT NACELLE VTOL AIRCRAFT



CS-79-1648

REPRESENTATIVE FIXED NACELLE VTOL AIRCRAFT



CS-79-1647

SUBSONIC VTOL PROPULSION TECHNOLOGY REVIEW

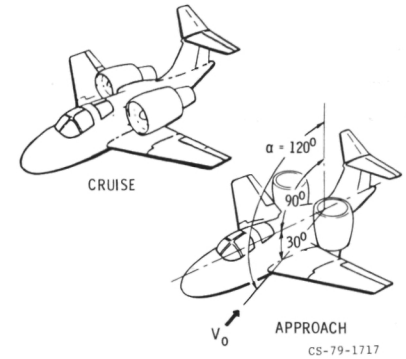
INLETS
- HIGH ANGLE-OF-ATTACK CAPABILITY
- EFFECT ON FAN BLADE STRESS

THRUST MODULATION
- VARIABLE PITCH FAN
- VARIABLE INLET GUIDE VANE FAN

PROPULSION CONTROLS
- PILOTED SIMULATION
- AIRCRAFT/PROPULSION CONTROL INTEGRATION

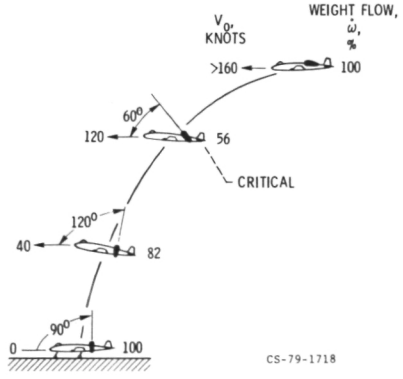
CS-79-1642

TILT NACELLE V/STOL AIRCRAFT



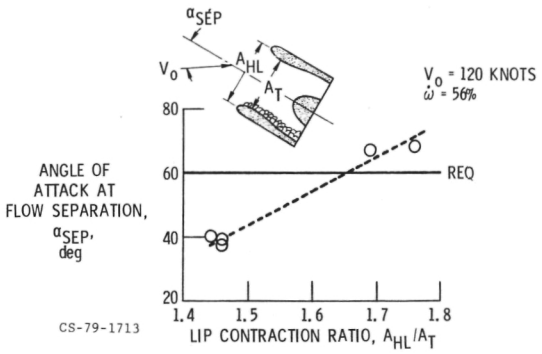
CS-79-1717

APPROACH FLIGHT PATH



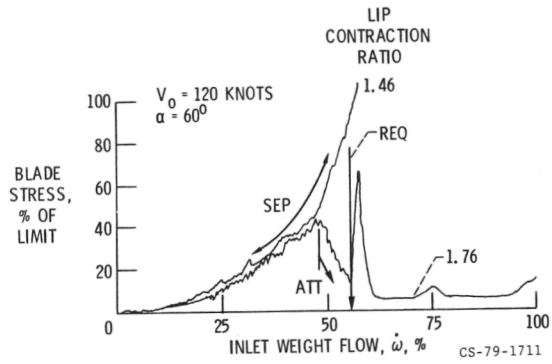
CS-79-1718

EFFECT OF INLET LIP CONTRACTION RATIO ON FLOW SEPARATION



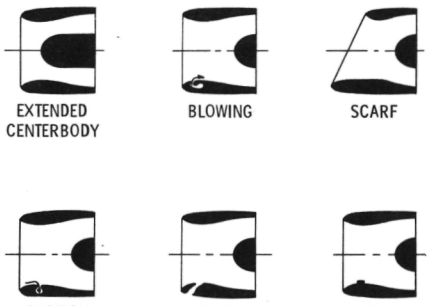
CS-79-1713

FAN BLADE STRESS



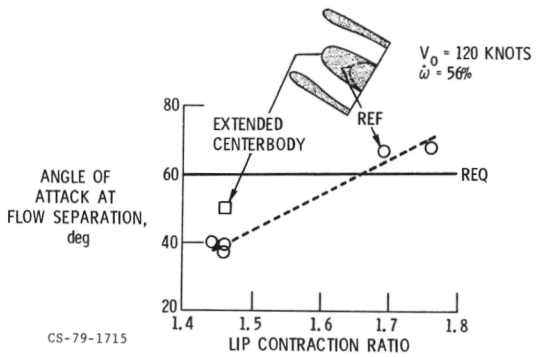
CS-79-1711

METHODS TO PREVENT FLOW SEPARATION



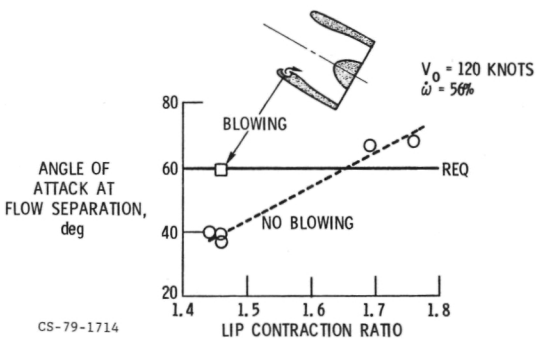
CS-79-1716

EFFECT OF EXTENDED CENTERBODY



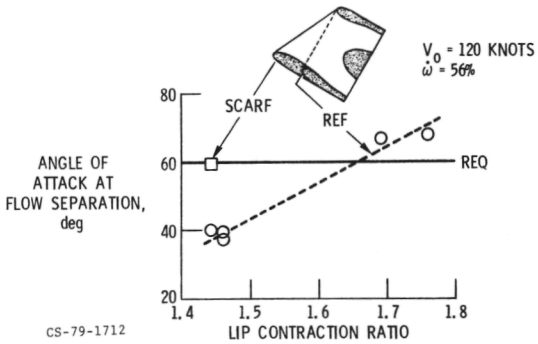
CS-79-1715

EFFECT OF BLOWING



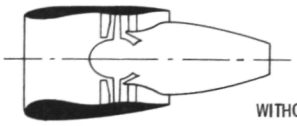
CS-79-1714

EFFECT OF INLET SCARF

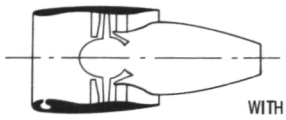


CS-79-1712

BENEFIT OF BLOWING



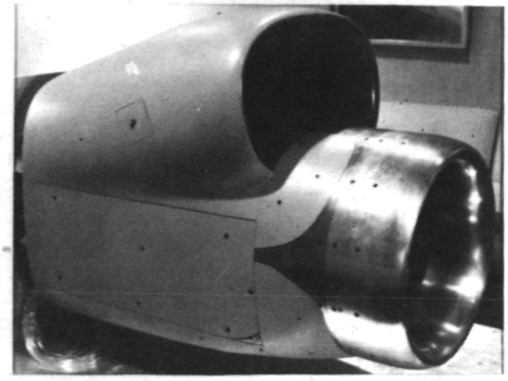
WITHOUT LIP BLOWING



WITH LIP BLOWING

CS-79-1710

TANDEM FAN INLET MODEL



SUBSONIC VTOL PROPULSION TECHNOLOGY REVIEW

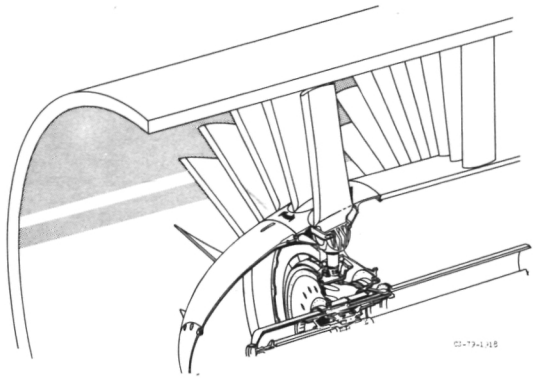
INLETS
- HIGH ANGLE-OF-ATTACK CAPABILITY
- EFFECT ON FAN BLADE STRESS

→ THRUST MODULATION
- VARIABLE PITCH FAN
- VARIABLE INLET GUIDE VANE FAN

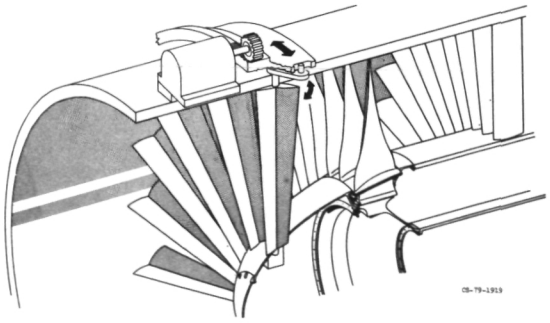
PROPULSION CONTROLS
- PILOTED SIMULATION
- AIRCRAFT/PROPULSION CONTROL INTEGRATION

CS-79-1645

VARIABLE PITCH FAN STAGE



VARIABLE INLET GUIDE VANE FAN STAGE



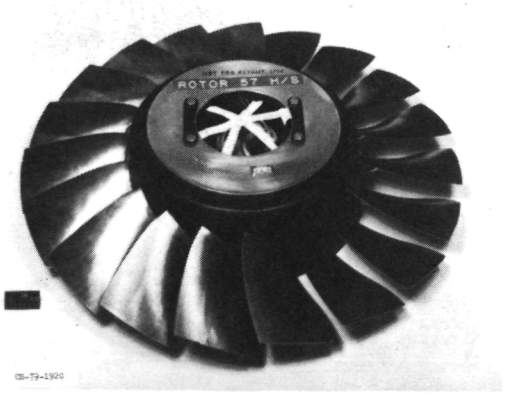
CS-79-1911

VARIABLE-PITCH FAN STAGE DESIGN PARAMETERS

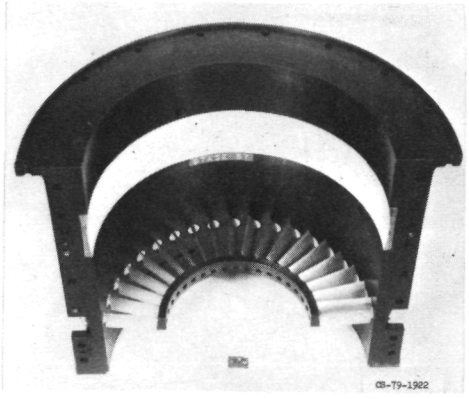
PRESS. RATIO	1.38
WT FLOW, lb/sec	65.3
SPECIFIC FLOW, lb/sec/ft^2	41.0
TIP SPEED, ft/sec	950

CS-79-1911

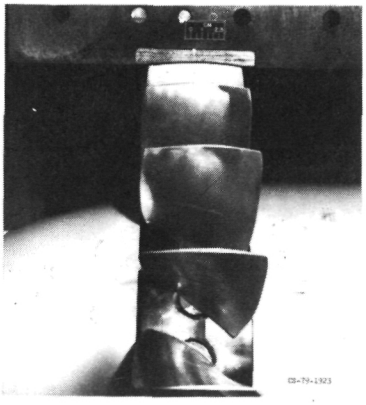
VARIABLE-PITCH ROTOR



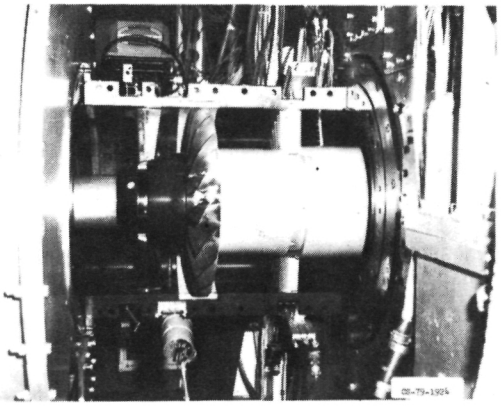
STATOR



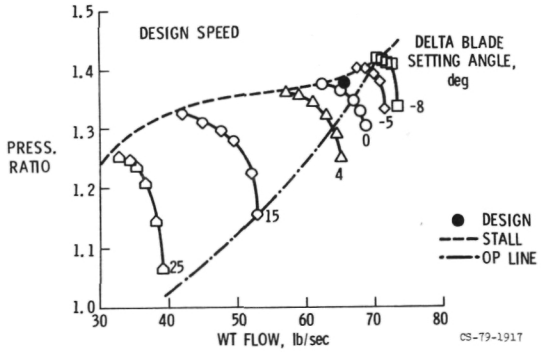
CASING-ROTOR TIP CONTOUR



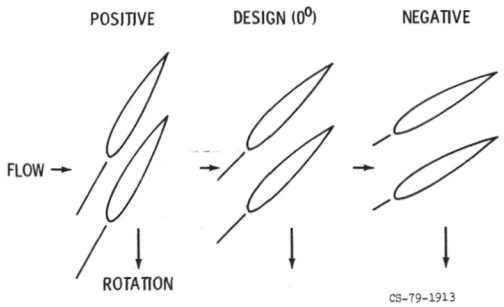
VARIABLE INLET GUIDE VANE FAN STAGE



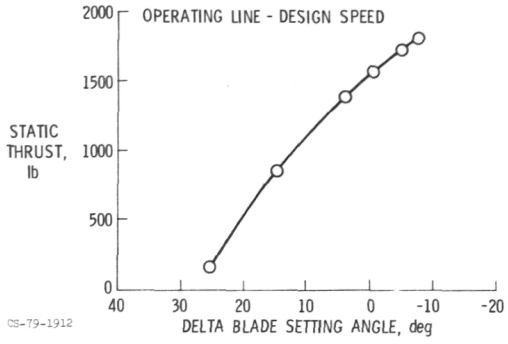
EFFECT OF SETTING ANGLE ON PERFORMANCE



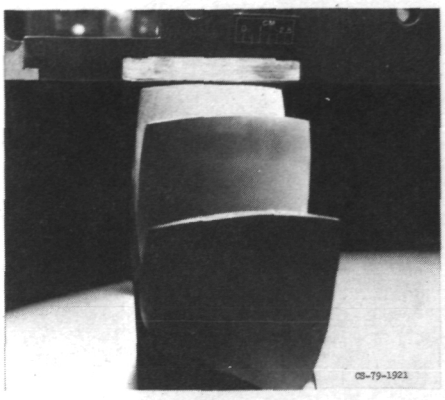
BLADE SETTING ANGLE



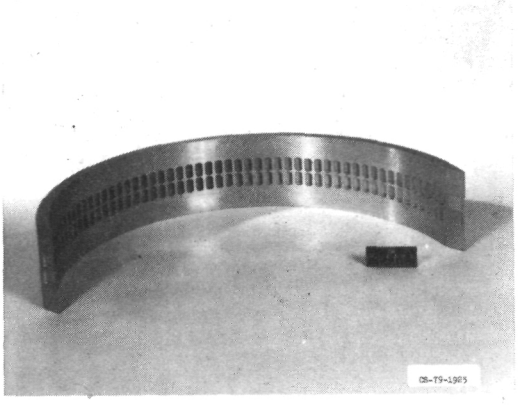
EFFECT OF SETTING ANGLE ON THRUST



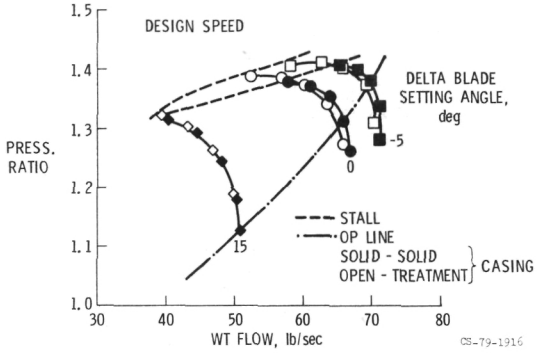
CYLINDRICAL INSERT



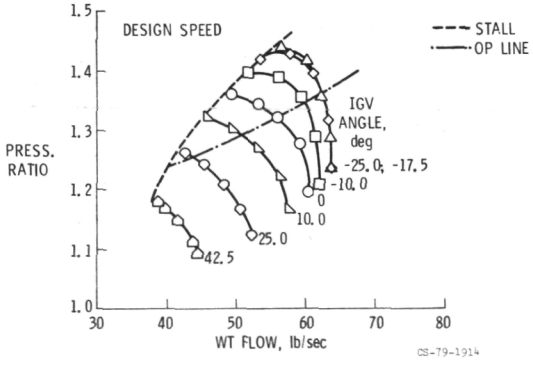
CASING TREATMENT INSERT



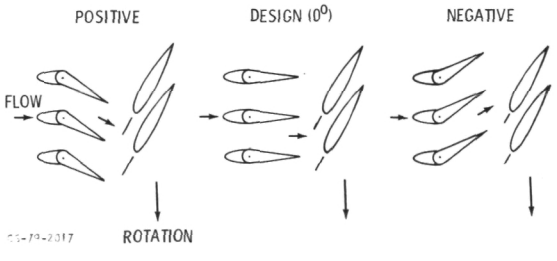
EFFECT OF CASING TREATMENT ON PERFORMANCE



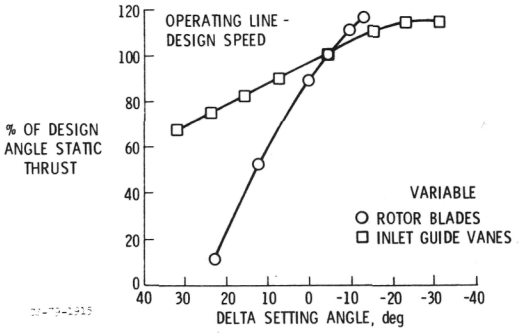
EFFECT OF VANE ANGLE ON PERFORMANCE



VANE SETTING ANGLE

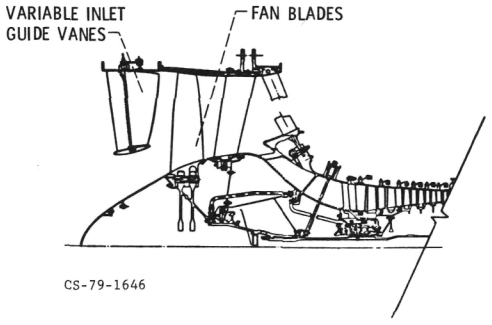


THRUST VARIATIONS



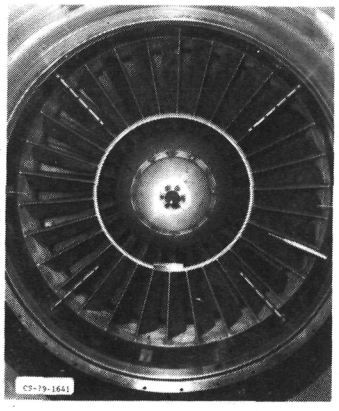
CS-79-1645

VARIABLE INLET GUIDE VANE ON TF 34 ENGINE

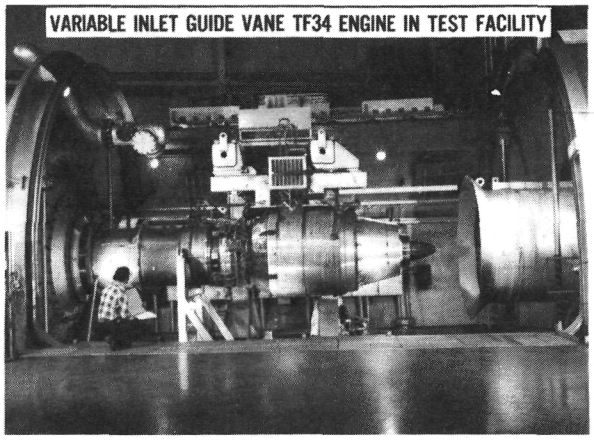


CS-79-1646

VARIABLE INLET GUIDE VANES MOUNTED ON TF-34 ENGINE



CS-79-1641



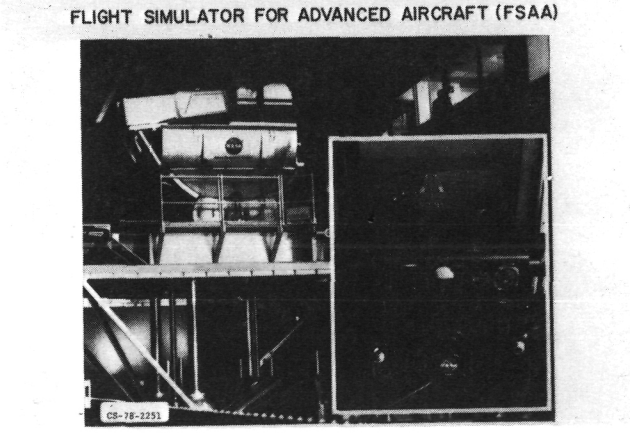
SUBSONIC VTOL PROPULSION TECHNOLOGY REVIEW

INLETS
- HIGH ANGLE-OF-ATTACK CAPABILITY
- EFFECT ON FAN BLADE STRESS

THRUST MODULATION
- VARIABLE PITCH FAN
- VARIABLE INLET GUIDE VANE FAN

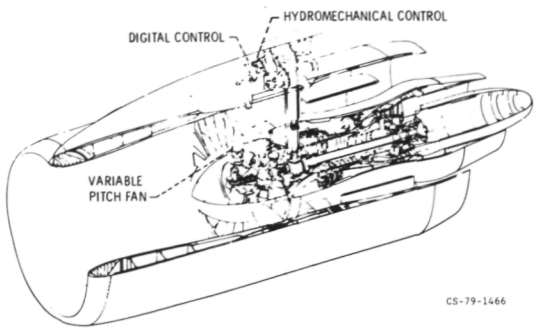
→ *PROPULSION CONTROLS*
- PILOTED SIMULATION
- AIRCRAFT/PROPULSION CONTROL INTEGRATION

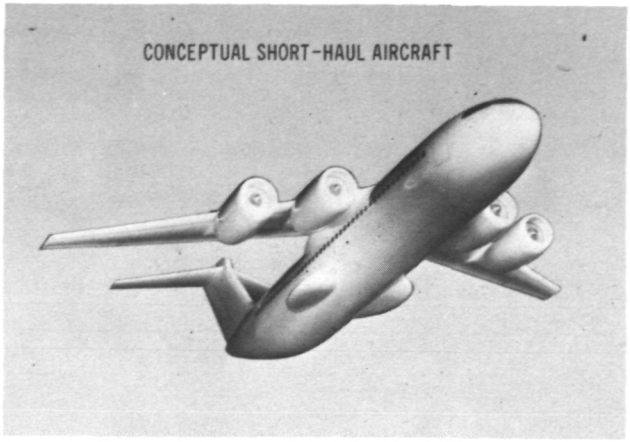
CS-79-1644



CS-78-2251

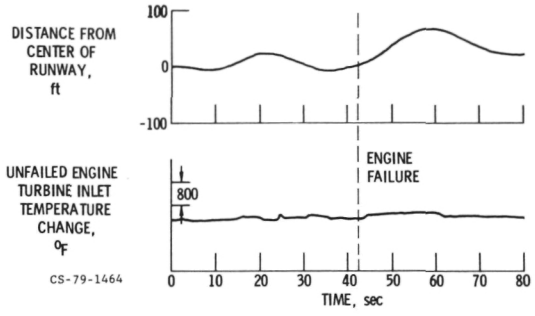
QCSEE EXPERIMENTAL PROPULSION SYSTEM





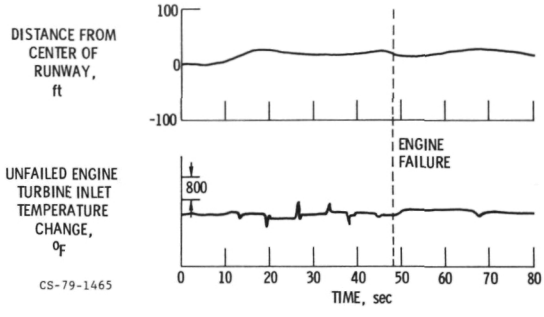
APPROACH WITH ENGINE FAILURE

WITH VISUAL CUEING ONLY

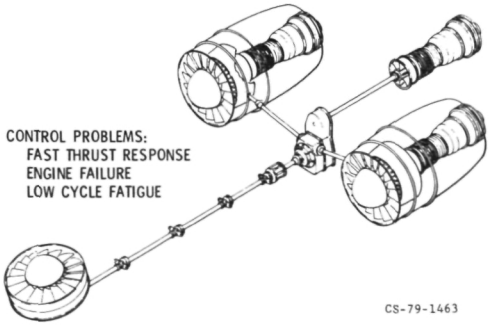


APPROACH WITH ENGINE FAILURE

WITH THRUST COMMAND COMPENSATION



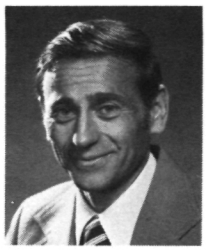
CONTROLS ANALYSIS FOR SUBSONIC VTOL PROPULSION SYSTEM



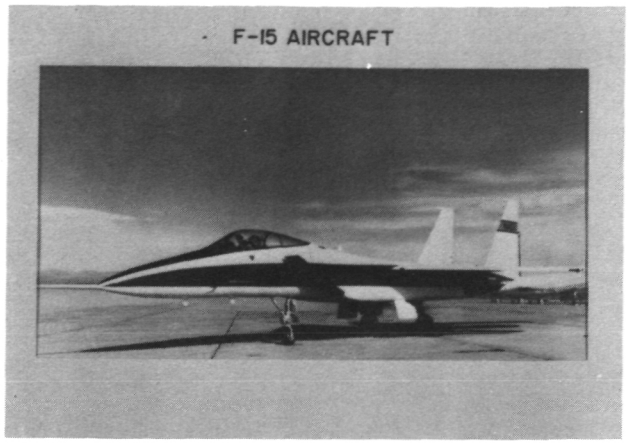
D14

XIV. HIGH PERFORMANCE VEHICLE TECHNOLOGY

Louis A. Povinelli



LOUIS A. POVINELLI joined the NASA Lewis staff in 1960 after a year of postdoctoral research at the Polytechnic Institute of Turin. He obtained a Ph.D. degree in engineering from Northwestern University, an M.S. degree from the University of Kentucky, and a B.S. degree from the University of Detroit. At Lewis, he has specialized in teaching compressible flow and in research on turbofan mixers and diffusers, rocket and turbojet combustion, and hypersonic propulsion. He has served as Associate Editor of the AIAA Journal and Chairman of the AIAA Propellants and Combustion Technology Committee.



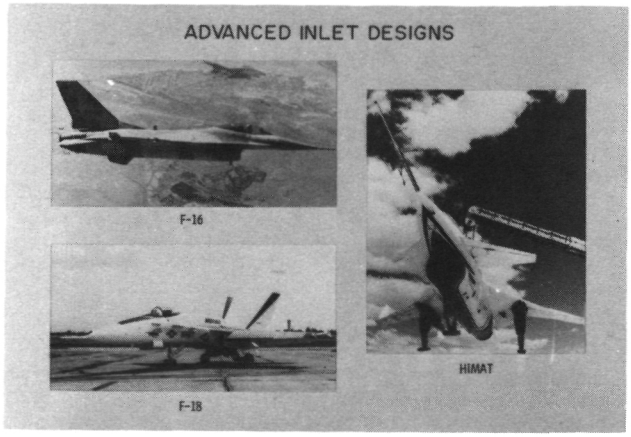
HIGH PERFORMANCE VEHICLE TECHNOLOGY

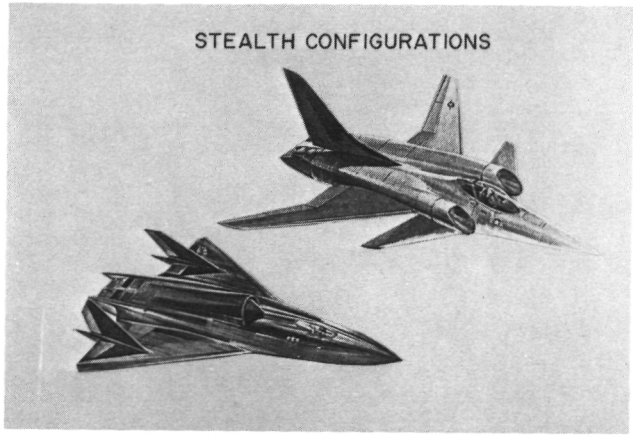
INLET PERFORMANCE

NOZZLE PERFORMANCE & COOLING

AFTERBURNER PERFORMANCE

CS-79-2193





GEOMETRICAL AND OPERATIONAL REQUIREMENTS FOR INLETS

HIGH DEGREE OF INTEGRATION WITH AIRFRAME

SIMPLE, LIGHTWEIGHT DESIGN, SHORT LENGTHS, LARGE OFFSET, GEOMETRIC TRANSITION

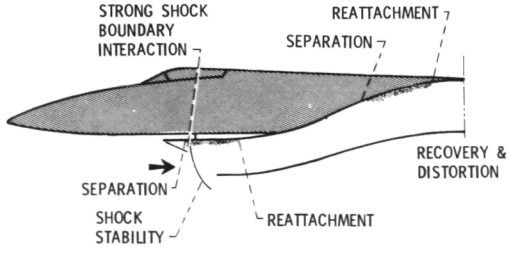
WIDE MACH NO. & ANGLE OF ATTACK CAPABILITY

STALL & BUZZ FREE OPERATION

LOW RADAR CROSS SECTION

CS-79-2195

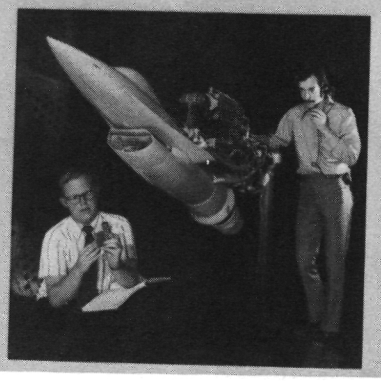
AERODYNAMIC FEATURES OF ADVANCED INLETS



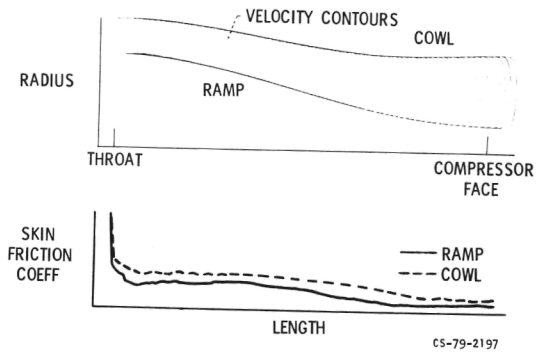
BOUNDARY LAYER CONTROL TECHNIQUES
VORTEX GENERATORS
BLEEDING
BLOWING

CS-79-2202

F-16 INLET MODEL TESTING IN LEWIS 8X6 TUNNEL



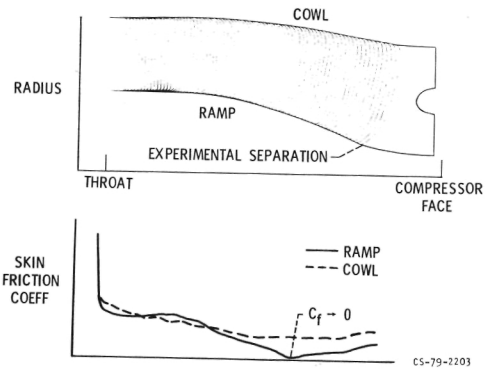
COMPUTER ANALYSIS OF F-16 INLET



CS-79-2197

HiMAT INLET TEST IN 8X6 TUNNEL

COMPUTER ANALYSIS OF HiMAT INLET



CS-79-2203

GEOMETRICAL AND OPERATIONAL REQUIREMENTS FOR NOZZLES

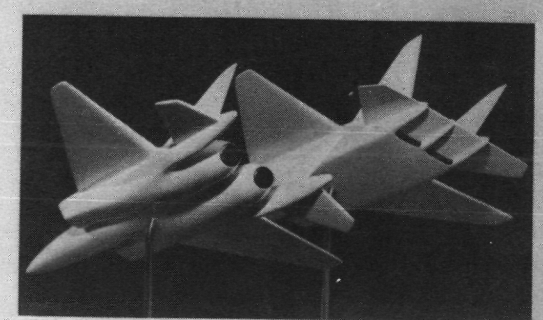
HIGH DEGREE OF INTEGRATION WITH AIRFRAME

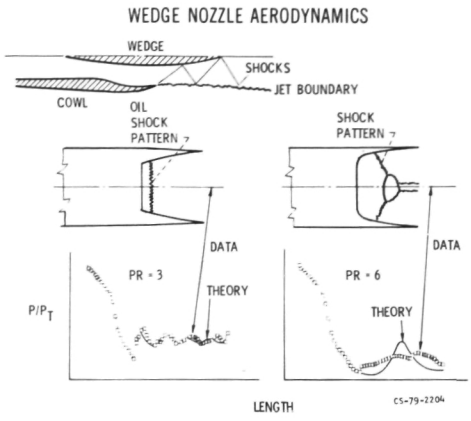
STEALTH CONSIDERATIONS

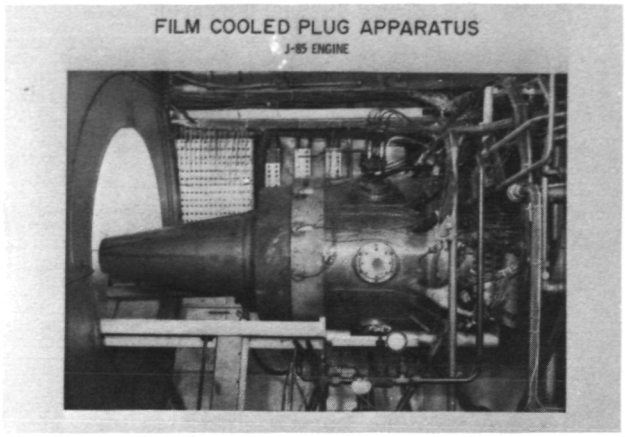
THRUST DEFLECTION & REVERSING

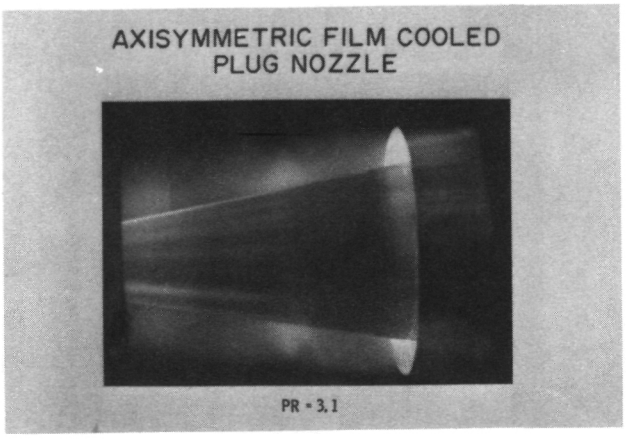
CS-79-2194

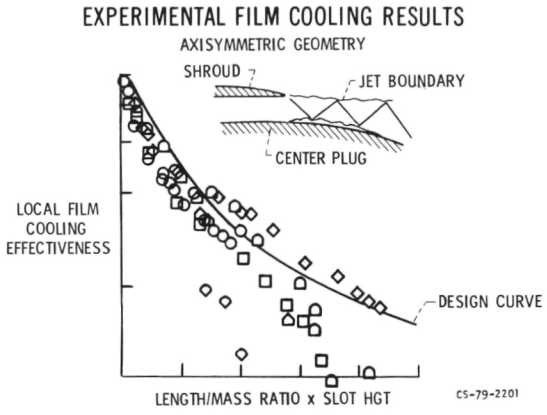
TWIN AXISYMMETRIC AND WEDGE NOZZLE INSTALLATION

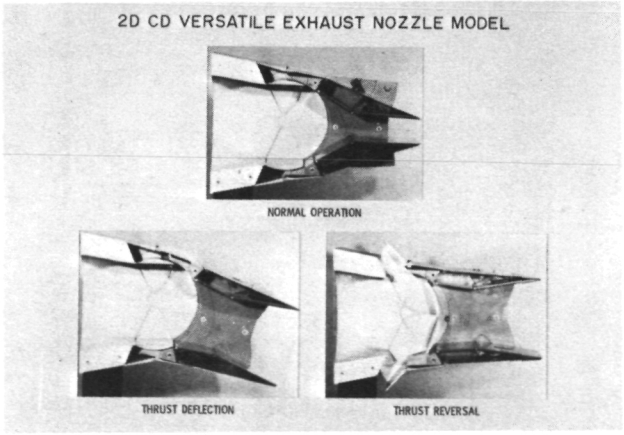












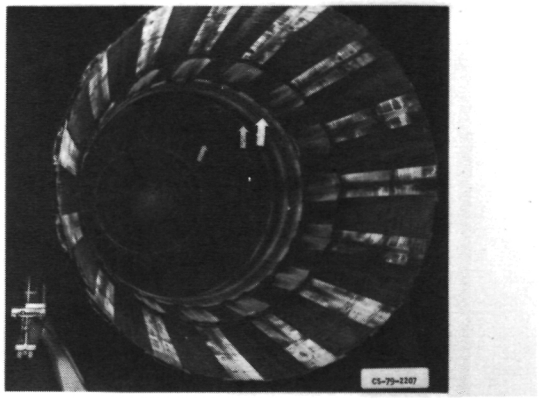
AFTERBURNER IMPROVEMENT GOALS

INCREASE ALTITUDE LIMIT FOR STABLE COMBUSTION WITHOUT RUMBLE

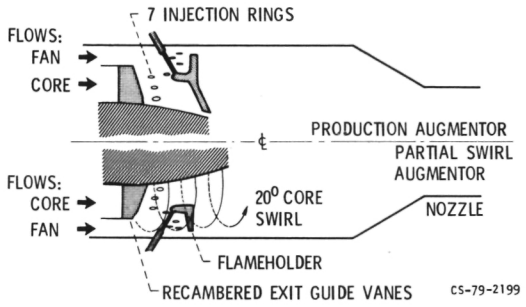
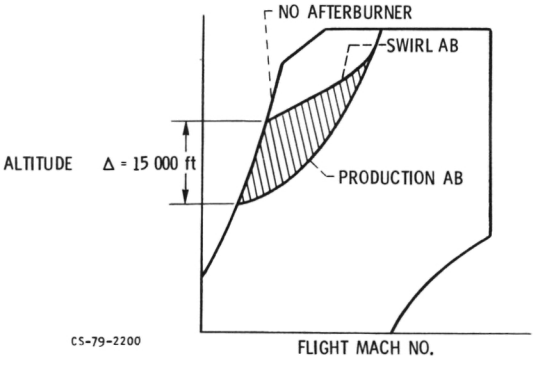
INCREASE BLOWOUT LIMIT FOR IDLE TO MAX AUGMENTATION THROTTLE TRANSIENTS

CS-79-2196

AFTERBURNER VIEW OF F-106 ENGINE



SWIRL AND PRODUCTION AUGMENTOR COMPARISON



EFFECT OF SWIRL ON AFTERBURNER